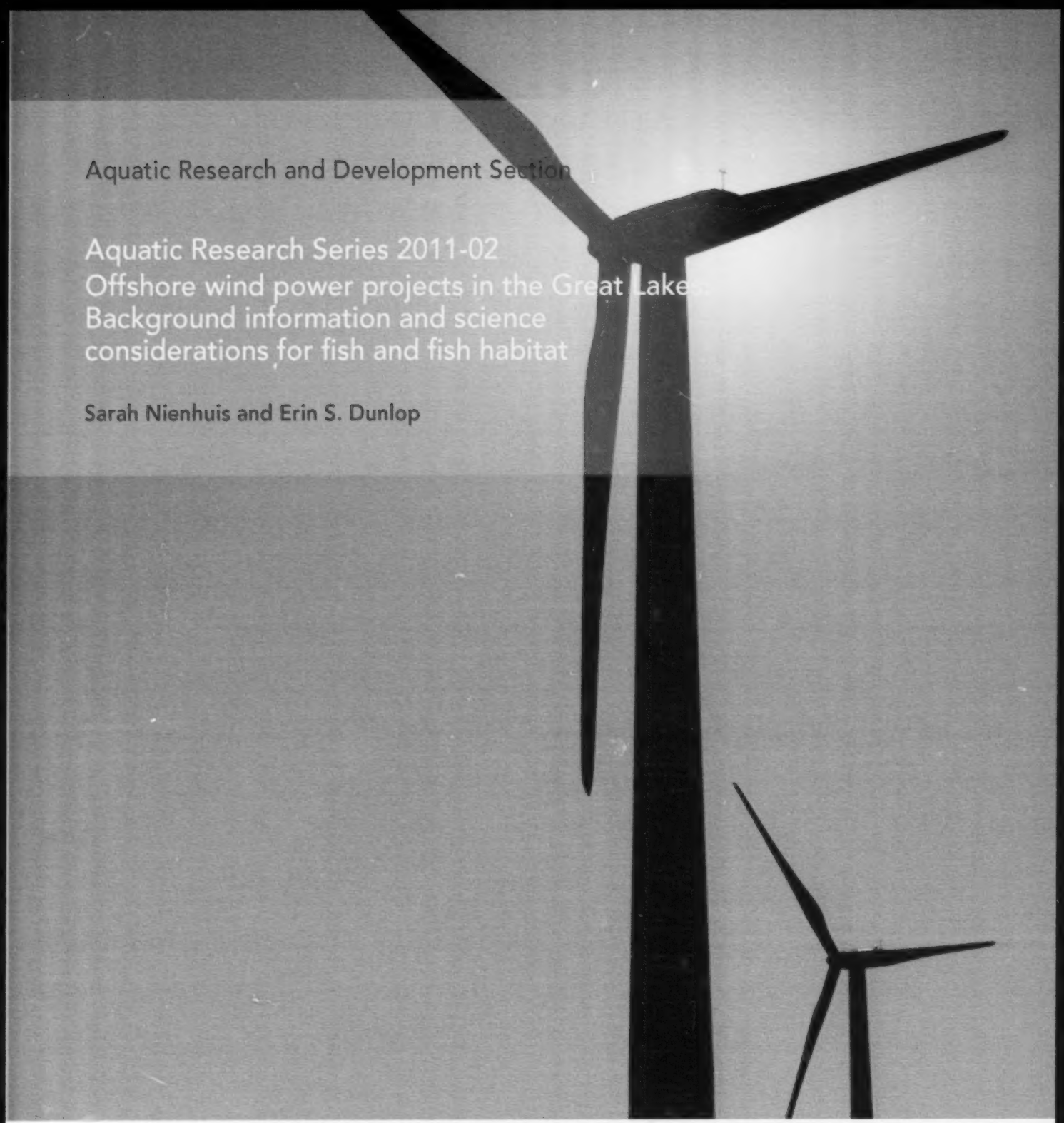

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Offshore wind power projects in the Great Lakes
Background information and science considerations for fish and fish habitat

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Offshore wind power projects in the Great Lakes: Background information and science considerations for fish and fish habitat

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Abstract

Owing to their large open fetches, which lend them stronger and more consistent wind speeds than onshore sites, the Great Lakes have been identified as potential future locations for offshore wind energy production. However, as with any large-scale in-water development project, consideration must be given to the potential environmental effects of offshore wind power projects in these important freshwater ecosystems. In a first report, we identified several potential effects of offshore wind power projects on fish and fish habitat within the Great Lakes. In this second report presented here, we take the next step of describing options available for preventing adverse effects and enhancing potential benefits within a Great Lakes context. Our goal is to examine the lessons learned from the marine offshore wind experience and other development projects in order to provide background information and science considerations that might help inform any future development of best management practices. In addition, we discuss the importance of comprehensive baseline and effects monitoring, identifying the types of data that will be particularly important to collect and reviewing the scientific tools and techniques necessary to detect and quantify the effects of offshore wind facilities on fish and fish habitat. Finally, we discuss the role that an adaptive management approach and the application of the precautionary principle can play in promoting the sustainable development of offshore wind facilities in the Great Lakes. We conclude by identifying key knowledge gaps and future research recommendations that, if addressed, will reduce our uncertainty of potential effects, inform options for preventing and mitigating adverse effects, and improve our ability to enhance benefits of offshore wind power projects within the Great Lakes.

Résumé

Étant donné le fetch – la vaste distance sans obstacles – qu'ils offrent aux vents, leur donnant ainsi plus de vitesse et d'uniformité que les sites sur terre, les Grands Lacs sont reconnus comme des sites potentiels pour la production d'énergie éolienne au large des côtes. Cependant, comme pour tout projet de développement de grande envergure sur des eaux, il faut prendre en considération les effets écologiques potentiels des projets éoliens en zone extracôtière sur les importants écosystèmes d'eau douce. Dans un premier rapport, nous avons dégagé un certain nombre d'effets possibles de ces projets sur les poissons des Grands Lacs et leur habitat. Dans le second rapport, que nous présentons ici, nous décrivons les options offertes pour prévenir les effets négatifs et accroître les avantages que pourraient offrir les projets éoliens dans le contexte des Grands Lacs. Notre objectif est d'examiner les leçons tirées des expériences éoliennes en mer et d'autres projets d'aménagement en mer pour offrir de l'information contextuelle et des observations scientifiques qui pourraient aider à informer l'élaboration future de pratiques de gestion exemplaires. Par ailleurs, nous examinons l'importance d'établir une station de référence de surveillance et une surveillance des effets, d'identifier les types de données qu'il faut recueillir, et d'examiner les outils et les techniques scientifiques nécessaires pour détecter et quantifier les effets des parcs éoliens en zone extracôtière sur les poissons et leur habitat. Enfin, nous nous penchons sur le rôle qu'une approche de gestion adaptative et l'application du principe de précaution peuvent jouer dans la promotion du développement durable de parcs éoliens sur les Grands Lacs. En conclusion, nous mentionnons des lacunes clés dans les connaissances et offrons des recommandations pour les études futures qui, si on en tient compte, réduiront notre incertitude quant aux effets possibles, nourriront les options visant à prévenir et à atténuer les effets négatifs, et amélioreront notre capacité à accroître les avantages que pourraient offrir les projets de production éolienne sur les Grands Lacs.

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Executive Summary

As jurisdictions consider the possible future installation of offshore wind power projects in the Great Lakes, there is an increasing need for developing best management practices and providing guidance related to the effects on the economically and ecologically valuable aquatic resources within these ecosystems. Although no offshore wind power installations currently exist in North America, offshore wind power projects in marine environments have existed for several decades in Europe. In a first, accompanying report, we reviewed available scientific and grey literature from the marine experience, and drew upon our knowledge of Great Lakes fish species, to identify the potential effects of offshore wind power projects on Great Lakes fish and fish habitat. In this second report, we take the next step of outlining the state-of-the-science on mitigation options, monitoring tools and techniques, and adaptive management and precautionary considerations related to those effects outlined in the first report. We also provide a basis for future work by identifying priorities and approaches for research and for addressing key uncertainties. While we do not develop best management practices here, our aim is for this report to provide the background information required for moving forward with the development of guidance related to offshore wind power projects in the Great Lakes and the considerations that need to be given to fish and fish habitat.

Key findings of this report include:

- In advance of any construction, consideration given as to site location and important biological periods will be critical for minimizing impacts to fish and fish habitat.
- Mitigation options are available for reducing impacts to fish and fish habitat; however, continued technological advancement and research will enable consideration and adoption of additional mitigation options within the Great Lakes.
- Even given precaution in choosing sites and best efforts to predict and avoid impacts, unforeseen effects could arise due to a lack of experience with wind power projects in freshwater; therefore, proper site-specific baseline and effects monitoring conducted over several years will be valuable and informative.
- Noise during construction is among the most serious effects to be considered; a soft start is the most common and feasible option to prevent noise-induced injury to fish from pile driving.
- Release of sediment-bound contaminants during construction activities is of particular concern in the Great Lakes; pre-construction, site-specific sediment surveys will enable proponents to identify the risk for contaminant release.
- There is evidence to suggest that lake trout could use turbine foundation scour protection materials as artificial reefs for spawning if they are designed appropriately.
- Key knowledge gaps include the spatial and temporal extent of operational noise and electromagnetic field effects on fish distribution, population dynamics, and recruitment.
- Adaptive management and applying the precautionary approach are methods available for incorporating uncertainty into the decision-making process; developing an explicit cycle for adaptive management for offshore wind would enable hypothesis-driven learning from the first few projects to guide future offshore development practices within the Great Lakes.
- Offshore wind power generation within the Great Lakes has the potential to be implemented with minimal impacts on the aquatic ecosystem if mitigation options are adopted, benefits are enhanced, learning is built into the management cycle, precaution is taken as to site location, and appropriate baseline and effects monitoring are conducted.

1. Introduction

As part of the international effort to reduce greenhouse gas emissions and mitigate impacts of global climate change, many nations are promoting the development of renewable energy technologies, including wind power generation, to replace fossil-fuel based energy production. Although offshore wind development is not yet a reality in North America, several proposals for projects along the oceanic coasts have recently been granted approval. Assessments of North American wind resources have demonstrated that owing to their large open fetches, the Great Lakes experience strong and constant wind speeds that make them candidates for wind power production as well. As a result, there is a growing interest within both U.S. and Canadian jurisdictions to consider the possible future development of offshore wind facilities in the Great Lakes.

While the Great Lakes have been identified as potential locations for development from a wind energy production point of view, they are also recognized as being unique and highly valuable freshwater ecosystems. Concern therefore exists that as with any large scale in-water development project, the installation of wind power facilities in the Great Lakes has the potential to impact fish and fish habitat—including ecologically and economically valuable species of fish. Upon review of the effects that have been observed to date at existing offshore wind power projects in marine environments, there are indications that the installation of wind turbines in the freshwater environment could impact Great Lakes fish species and habitats in a variety of ways as well (Nienhuis & Dunlop 2011). Thus, as governments set out to establish policy and regulatory guidance, and industry seeks to navigate approvals related to offshore wind facility development in the Great Lakes, there is a growing need to provide science-based guidance to enhance the benefits and minimize any potential negative impacts to these ecologically and economically important aquatic ecosystems.

Drawing from the marine literature as well as upon knowledge of Great Lakes ecosystems, a literature review and assessment of the potential effects of offshore wind power projects on Great Lakes fish and fish habitat has been conducted. Based on the findings of that report (Nienhuis & Dunlop 2011) it is clear that while uncertainty exists as to the severity or spatial extent of different types of effects, understanding and acknowledging the potential for impacts to the

aquatic ecosystem is an important consideration towards developing a sustainable approach to offshore wind energy production in the Great Lakes. Having identified the effects to fish and fish habitat that are likely to arise from offshore wind developments in the Great Lakes in our initial report, the next step is to determine how best to assess the significance of these effects, and to explore the options available for preventing adverse effects and enhancing potential benefits within a Great Lakes context.

In this second report, we examine the lessons learned from the experiences of marine offshore wind and other development projects in order to provide background information and science considerations to support the future development of best management practices related to offshore wind power in the Great Lakes. To this end, the importance of comprehensive baseline and effects monitoring studies are discussed, as are the scientific tools and techniques necessary to detect and quantify the impacts of offshore wind facilities to fish and fish habitat. We identify the types of data that will be particularly important to collect in such studies, focussing on those effects likely to pose the greatest environmental risk, or those associated with the greatest degree of uncertainty. In addition, we evaluate the strategies that have been used in other development projects for avoiding or mitigating the potential negative impacts of offshore wind power-related activities or installations to fish and fish habitat, and suggest several Great Lakes-specific options for enhancing the potential benefits of wind turbine structures as well. Finally, we discuss how the adoption of an adaptive management approach and the application of the precautionary approach are options available to promote the sustainable development of offshore wind facilities in the Great Lakes; we do this in part by highlighting the approach to offshore wind development taken by several other countries. We conclude by identifying key knowledge gaps and future research recommendations in order to enhance our ability to understand, predict and prevent potential adverse ecological impacts of offshore wind power projects within the Great Lakes.

2. Preventing, minimizing and mitigating negative impacts

As with any large-scale offshore development project, the construction and operation of offshore wind power facilities has the potential to affect the aquatic environment. Through increasing experience with offshore construction activities—whether they be for offshore wind power projects in the marine environment, for the oil and gas industry, or for coastal engineering works

or other in-water installations—a growing awareness and understanding of possible effects as well as solutions to manage and reduce environmental risk continues to evolve. Recently, much research and development has been focussed on finding effective and innovative measures to prevent or reduce disturbance to aquatic ecosystems and their inhabitants and promote sustainable in-water development practices. In this section, we review strategies employed for offshore development projects and identify the options currently available for avoiding, minimizing and mitigating those potential effects of wind power projects in the Great Lakes that were previously identified (Nienhuis & Dunlop 2011). A summary of the available options can be found in Table 1.

2.1 Site selection and construction timing windows

The avoidance of environmentally sensitive areas or critical biological periods is probably the most certain way to minimize potential adverse effects to Great Lakes fish and fish habitat during the construction of offshore wind power projects. Sensitive areas would include those characterized by high levels of species diversity or productivity; areas known to house critical spawning, nursery or foraging habitat for species at risk or other economically or ecologically valuable fish species; migration corridors; and habitats already under threat from cumulative impacts including land use changes, sedimentation, invasive species, and climate change. Critical biological periods include fish spawning seasons, egg and fry incubation and development periods, and seasonal migrations.

In order to make informed decisions regarding site selection and construction timing, knowledge of the existing biological communities and habitat types within a proposed project area, and of the timing windows when different fish species would be expected to utilize the area is necessary. Here we give examples of how project location and construction timing can significantly influence the degree of impact that the construction of a given offshore wind power project will have on nearby fish and fish habitat.

Table 1. Mitigation strategies for potential impacts of offshore wind power projects to fish and fish habitat in the Great Lakes. This table follows a similar structure to Table 1 in the first report outlining potential effects (Nienhuis & Dunlop 2011).

Effect	Associated wind power activity	Predicted magnitude of effect without mitigation (uncertainty)	Mitigation strategy	Examples of specific mitigation measures	Examples of potential limitations for application in the Great Lakes
Disturbance or injury to fish from underwater noise during construction	Construction (mainly pile driving)	High (Low)	• Warning or deterring fish from area in advance of pile driving or dredging	• Slow or soft start; Strobe lights	
			• Reducing noise transmitted into surrounding aquatic environment	• Air bubble curtains; Isolation casings and cofferdams; Noise dampening devices; Reducing number of pile strikes by using pre-drilling or water jetting	• Strong currents and waves and deep waters might limit applicability of bubble curtains; Cofferdams more difficult to install and dewater in deep water
			• Alternatives to pile driving	• Vibropiling; Press in piling	• Not feasible for all substrate types; Vibropiling might increase turbidity; Press in piling currently limited to small monopiles
			• Reducing disturbance from boat noise	• Limit vessel speed and route	
			• Type of dredge used	• Use mechanical dredges instead of suction hopper dredges	• Mechanical dredges increase turbidity
Release of contaminants	Construction (dredging, cable trenching)	High (Low)	• Project location	• Avoidance of areas with high concentration of contaminants	• Sites with low contaminants might have high biodiversity, valuable tourism operations, etc.

Effect	Associated wind power activity	Predicted magnitude of effect without mitigation (uncertainty)	Mitigation strategy	Examples of specific mitigation measures	Examples of potential limitations for application in the Great Lakes
Release of contaminants cont.	Construction (dredging, cable trenching)	High (Low)	• Use barriers that minimize spread of contaminated sediments into surrounding aquatic environment	• Silt curtains and other types of turbidity barriers	• Strong currents and waves might limit use
Disturbance to fish from underwater noise during operation	Turbine operation	Medium (High)	• Reduce sounds from gearbox	• Direct driven generators (no gearbox needed)	• Technology not yet widely available for large turbines
			• Reduce rotational speed of turbine blades	• Variable speed turbines; Pitched blades	
			• Choice of foundation type	• Concrete gravity instead of steel monopole	• Tradeoffs with other effects of gravity foundations such as increased habitat loss
			• Use noise or vibration minimizing materials	• Insulate gearbox, below water structures, and foundation (e.g. insert layer of foamed polymer between tower and water)	
Disruption of fish distribution or migration and harm to sensitive life stages (eggs and fry) from electromagnetic fields	Operation of submarine power cables	Medium (High)	• Reduce strength of electromagnetic field emitted into aquatic environment	• Cable burial; Cable armouring or sheathing; Core twisting	• Cable burial will increase risk for other impacts such as increased turbidity and habitat loss from dredging; Given long cable routes, burial might not be feasible in all cases
			• Alter cable route	• Avoid areas or habitats with sensitive species or life stages	

Effect	Associated wind power activity	Predicted magnitude of effect without mitigation (uncertainty)	Mitigation strategy	Examples of specific mitigation measures	Examples of potential limitations for application in the Great Lakes
Sedimentation and turbidity from construction activities	Construction (dredging and cable trenching)	Medium (Low)	• Minimizing disturbance during cable laying	• Single-operation process (i.e. trenches excavated and cables buried at once); Placing cables on top of lake bed (instead of burial); Horizontal directional drilling below lakebed of sensitive nearshore areas for cable landfall; Cofferdams	• Not burying cables might increase EMF exposure, potential fishing gear entanglement, and damage or movement from ice; Horizontal directional drilling increases chance of "frac-outs" which cause release of drilling muds and fluids
Sedimentation and turbidity from construction activities (cont'd)	Construction (dredging and cable trenching)	Medium (Low)	• Foundation type	• Monopile instead of gravity-based	• Pile driving of monopiles will cause noise disturbance
			• Choice of dredging equipment	• Use hydraulic dredges that reduce siltation instead of mechanical dredges	• Hydraulic dredges create more noise than mechanical dredges
			• Controlling turbidity	• Silt curtains and other turbidity barriers; Bubble curtains; Restrict dredging to low wind and wave energy periods	• Strong currents and waves might limit capability of using turbidity barriers or bubble curtains
Negative impacts from invasive species colonizing turbine structures and scour protection	Physical presence of structures	Low (High)	• Project location	• Avoid project placement in boundary areas	• Could prove very difficult to predict or control range limits
			• Periodic removal	• Mechanical removal of encrusting invertebrates	
			• Deterring colonization and use by non-native species	• Choice of scour protection materials that reduce colonization; Use anti-fouling agents to limit colonization	• Anti-fouling chemical agents could cause water quality issues

Effect	Associated wind power activity	Predicted magnitude of effect without mitigation (uncertainty)	Mitigation strategy	Examples of specific mitigation measures	Examples of potential limitations for application in the Great Lakes
Loss of access to recreational and commercial fishing	Construction and operation	Low (Medium)	• Reduce potential for gear entanglement which could necessitate restricted access • Timing windows for construction activities to minimize or avoid harm and disruption to commercial species • Project location	• Cable burial; Consider alternative fishing gear and practices to minimize gear entanglement • Avoid construction during spawning times or traditional fishing seasons • Minimize development in traditional or productive fishing grounds	• Cable burial will increase risk for other impacts such as increased turbidity and habitat loss from dredging
Alteration of currents, wave strength, and wave direction	Physical presence of structures	Low (Medium)	• Turbine configuration • Project location	• Modify the layout of turbines so as to minimize effects to currents and waves • Avoid development in areas where altered currents are predicted to have large effects	• Some areas might have limited suitable sites for development from a wind energy or construction perspective
Altered sediment transport and deposition from physical presence of turbines and foundations	Physical presence of structures	Low (Medium)	• Minimize formation of scour pits • Turbine and foundation design and configuration • Project location	• Scour protection • Streamlining component shapes; Reducing size and surface area • Avoid development adjacent to areas sensitive to changes in sediment dynamics	

Effect	Associated wind power activity	Predicted magnitude of effect without mitigation (uncertainty)	Mitigation strategy	Examples of specific mitigation measures	Examples of potential limitations for application in the Great Lakes
Habitat loss	Dredging activities; Physical area occupied by turbine foundations and cables	Low (Low)	• Use smaller footprint foundation types	• Monopile instead of gravity-based	• Pile driving of monopiles will cause noise disturbance
			• Minimize nearshore disturbance	• Horizontal directional drilling; Jet ploughing or other single-operation process for cable burial	• Horizontal directional drilling increases chance of "frac-outs" which cause release of drilling muds and fluids
			• Cable laying considerations	• Avoid cable burial; Plan cable route to avoid critical or sensitive habitat	• Not burying cables might increase transmission of EMFs, potential fishing gear entanglement, and damage or movement from ice

Many adverse effects to fish and fish habitat resulting from construction activities—including injury or disturbance from noise, reduced foraging efficiency or egg smothering from dredging-related turbidity, and direct benthic habitat loss as a result of turbine foundation installation—could be minimized by simply avoiding construction in areas known to support large populations of fish or which contain critical habitat features utilized by sensitive life history stages or species. Similarly, submarine cable routes could be planned or altered so as to avoid disturbance to sensitive areas that might otherwise be intersected, including spawning shoals or coastal wetlands. During cable or pipeline installation, if underwater video or scuba divers identify unexpected sensitive features such as spawning reefs, it is not uncommon for developers to alter the originally planned cable route to circumvent and thereby protect these features. Cable route planning could also incorporate considerations of migration corridors given the possibility that emitted electromagnetic fields could cause disorientation and interfere with the migratory behaviour of certain fish species. Finally, because it could be a significant concern within certain Great Lakes regions, in order to reduce the potential for sediment-bound contaminants to be re-suspended and become biologically available, the most obvious preventative action would be to avoid dredging or drilling in areas with fine-grained sediments known to contain high concentrations of persistent organic or heavy metal contaminants.

Just as site selection will be critical to preventing certain adverse impacts to fish and fish habitat, so too will the timing of construction be important to consider. To reduce interference with spawning, egg incubation, and fish migrations, one option is to set appropriate in-water work windows or time-of-year restrictions for potentially damaging activities like pile driving or dredging. Working around these critical biological periods could help to constrain detrimental effects to timeframes that will minimize impacts. Fisheries and Oceans Canada has existing guidelines for Ontario in-water construction timing for the protection of fish and fish habitat, which restrict or forbid certain activities during spawning migrations and other critical life history stages (Fisheries and Oceans Canada 2010a). Regional restricted activity timing windows for the protection of spawning fish and developing eggs and fry have been identified by Fisheries and Oceans Canada, and could be considered for offshore wind power developments. With regards to noise from operating wind turbines, which could potentially mask fish communication and interfere with spawning (Nienhuis & Dunlop 2011), one option is periodic turbine shut

downs or reduced operating speeds during critical spawning periods of nearby fish species. Similar recommendations have been developed to protect birds and bats from wind turbine collisions during large-scale migrations.

While precautionary selection of wind power project locations and the timing of construction activities will help minimize the impacts reviewed in our previous report (Nienhuis & Dunlop 2011), there are also a number of additional options to reduce or mitigate some of the specific effects of offshore wind developments on Great Lakes fish and fish habitat. What follows is a detailed review of these existing mitigation strategies, including a discussion of their feasibility and potential limitations for application in the Great Lakes.

2.2 Mitigating noise: reducing noise levels during construction

Having reviewed the potential impacts of offshore wind power projects to Great Lakes fish (Nienhuis & Dunlop 2011), noise emerges as one of the more significant effects to be considered. In particular, combined noise levels arising from activities like pile driving, dredging and the use of heavy machinery during the construction phase can reach sufficient intensity to cause physiological harm or mortality to nearby fish, with pile driving noise documented to have caused fish kills within 50 m (Caltrans 2001). Given the potential for loud noises to injure fish and other aquatic organisms, proponents involved in offshore construction projects (primarily in the marine environment) have developed and implemented a variety of strategies to reduce or mitigate the damaging potential of construction-related noise in the underwater environment.

Pile driving noise

Because it generates some of the highest underwater sound pressure levels of any anthropogenic activity, most of the available options for noise reduction have been developed specifically for pile driving. In addition to being used for the installation of monopile turbine foundations for the offshore wind industry, pile driving is also commonplace during the construction or repair of large bridges, wharfs and piers. In fact, much of the research and development focussed on noise mitigation for pile driving has been driven by concerns raised over hydroacoustic effects to marine fish and mammals during monopile installation for various bridge projects off the California coast. To this end, the California Department of Transportation has recently developed technical guidance for the mitigation of pile driving noise, identifying and describing various

options or technologies to reduce harmful sound levels (Caltrans 2009). Similar strategies have been adopted for other offshore construction projects in the U.S. and abroad, including offshore wind turbine installation. Despite having largely been developed for use and tested in the marine environment, to our knowledge there is no reason that similar technologies or strategies could not be adapted for use in freshwater ecosystems as well.

The various concepts that have been developed to mitigate or minimize injury to fish and other organisms during pile driving activity can be divided into three categories. The first involves methods to deter or warn mobile organisms away from the area of impact, thereby preventing their exposure to the loudest sound pressure levels near the source (acoustic deterrence techniques). The second strategy is to reduce the propagation of high pressure sound waves emanating from the source, in this way limiting the detection distance and zone of impact of pile driving noise (acoustic decoupling techniques). Finally, there are also technologies designed to dampen or decrease pile driving sound levels directly at the source (reducing noise levels at the source). Here we review the existing options within each category, assessing their efficacy at reducing potential injury to fish, and evaluating their feasibility for use during wind turbine installation in the Great Lakes.

Acoustic deterrence techniques: slow or soft start method

One of the most common approaches to mitigate exposure and potential injury to aquatic organisms from pile driving activity is to adopt a slow or soft start. Employing this method, initial hammer blows to the monopile are delivered with less force and less frequency than the eventual full-strength, full-speed pile driving. In the offshore environment, this method has been implemented for bridge construction and more recently for the installation of monopile-foundation wind turbines. During construction of an offshore wind power project in the Moray Firth in NE Scotland, for example, a soft start was adopted during monopile installation which consisted of five strokes of the hammer at low energy, each separated by 5, 3, 2, and then 1 minute. Following this, the hammer energy was slowly increased, or ramped-up, over a period of 20 minutes, after which full-force impact pile driving commenced (Bailey *et al.* 2010). Similar slow starts were also used as a noise mitigation measure during construction at both the Horns Rev and Nysted wind power projects off the Danish coast (Tougaard *et al.* 2003).

The rationale behind the soft start concept follows from acoustic deterrence techniques. The idea here is that the initial, low-impact hammer blows create enough noise disturbance to trigger a behavioural avoidance response among nearby mobile organisms, causing them to swim away from the source of the sound, without causing physiological harm. Conducting these initial blows intermittently, gradually increasing the energy and frequency of hammer strikes, can alert animals in the vicinity to the commencement of operations, allowing them ample time to swim away from the area of impact before potentially injurious noise levels are reached. Underwater sound recordings taken during monopile installation at the Scottish site demonstrated that the soft start did successfully result in a gradual increase in sound pressure levels (Bailey *et al.* 2010). Though the investigators suggest that this measure could have warned animals away from the area before harmful levels were reached, they note that there have yet to be studies specifically documenting this.

Of all options available for potentially mitigating noise-induced injury to fish during pile driving activity in the Great Lakes, the ramp-up or soft start technique will likely prove the most feasible measure for wind power project developers to adopt. This method does not require the use of any additional specialized equipment, and while it is inefficient for construction initially, employing a 30-odd minute soft start procedure is not likely to result in any significant construction delays. Unfortunately, this technique would only be effective at scaring off mobile organisms, such as non-territorial adult fish. For those organisms or life history stages (including fish eggs and fry) that are unable to swim away from the area of impact, a slow or soft start would do very little towards protecting them from the hydroacoustic effects of pile driving. This option also does not reduce the area of impact once full-force pile driving has been initiated.

Acoustic deterrence techniques: other options

Other options have been developed to deter mobile fish from areas where injury or mortality is likely. For example, the use of bubble screens to divert or exclude fish from certain areas has been proposed for various applications, including recently as a potential mechanism to control the spread of Asian carp through tributaries and into the Great Lakes. Laboratory experiments with alewife, smelt and gizzard shad, all Great Lakes pelagic fish, demonstrated that an air bubble screen successfully prevented the passage of all species across the screen, thereby acting as an effective exclusion barrier (Patrick *et al.* 1985). Where air bubble curtains were used early

on in the field to prevent fish movement near power plant intakes, mixed success was noted—they were ineffective at night and under turbid conditions. Furthermore, additional studies have found that the response of fish to air bubble screens is inconsistent, with bottom-dwelling species like white sucker, spot and white perch displaying attraction to the bubbles, rather than avoidance (Patrick 1984; Sager 1984). Whether bubble screens could be an effective deterrent to prevent fish from entering zones of high sound pressure levels during pile driving is unclear. However, if they are used as sound attenuating devices (see below) air bubble curtains could have the added benefit of acting as behavioural deterrents.

Another technique that could be used to deter fish from the construction zone and prevent their exposure to damaging noise levels during pile driving involves the use of light, to which fish generally respond with avoidance. Specifically, the use of strobe lights, either alone or in combination with air bubble screens, has been proposed to exclude fish from dangerous areas near power plants or dams. Laboratory studies conducted on selected freshwater and estuarine species showed that all species exhibited significant avoidance behaviour to strobe lights (Patrick *et al.* 1985). In the same study, when strobe lights were used in combination with bubble screens, avoidance was further increased, especially under dark conditions where bubble screens alone had limited success. More recently, strobe lights were shown under laboratory conditions to act as an aversive stimulus for zebrafish, effectively deterring them from entering preferred areas (Mesquita *et al.* 2008). However, the zebrafish habituated to the stimulus after approximately 20 minutes, indicating that the efficacy of this particular deterrent might only be temporary. The ability of strobe lights to deter fish under field conditions has yet to be fully investigated, and could be more effective in shallow water streams or rivers than in the deeper waters where wind turbines are likely to be installed.

Acoustic decoupling techniques

In addition to employing methods to deter or warn mobile organisms away from the area of hydroacoustic impact during pile driving, there are a number of options available to reduce or attenuate the transmission of high pressure sound waves underwater, thereby limiting the detection distance and zone of impact. Specialized equipment has been developed to essentially isolate the piles from the water column—through which sound waves would otherwise effectively travel—in this way creating a barrier to sound propagation. The introduction of an

intermediary medium or material that has stronger sound attenuation properties (i.e. causes sound to dampen to a greater extent) than water effectively decouples the pile from the fluid, and inhibits the spreading of sound pulses out into surrounding areas. There are several devices that have been designed to do just this, though one of the most common is the air bubble curtain.

Air bubble curtains – Air bubble curtains are essentially a dense screen of air bubbles generated by forcing compressed air through a perforated tube or pipe that encircles the base of a pile (Fig. 1). The resulting curtain of air bubbles should ideally ascend to the water surface and completely surround the pile. Owing to the difference in density between air and water, the difference in sound wave propagation between the two media, and the scattering, reflection and absorption of sound waves by gas bubbles in water, this screen of bubbles can provide an effective barrier to inhibit the propagation of sound from a hammered pile.

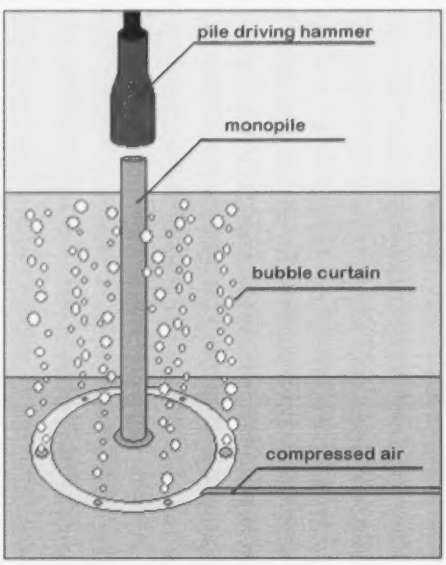


Figure 1. Air bubble curtain concept. The screen of air bubbles surrounding the monopile can attenuate the propagation of sound from a hammered pile and reduce the potential for injury to fish from the high-intensity sound pressure levels generated by pile driving activity.

Where they are feasible for use, air bubble curtains could therefore significantly reduce the potential for injury or mortality to nearby fish because of their ability to reduce sound levels. In a study conducted by the California Department of Transportation (Caltrans 2004), it was found that caged rainbow trout held in the vicinity of pile driving operations sustained less

physiological trauma in the presence of an air bubble curtain than those exposed to un-attenuated pile driving noise. More studies of this kind are clearly necessary to determine the degree of protection that this option might afford to different species and life stages of fish. However, the fact that properly designed and deployed air bubble curtains have achieved consistent reductions in pile driving sound pressure levels of at least 5-10 dB, indicates that this option might well be an effective strategy for reducing detrimental noise effects to fish and other organisms.

The first reported successful use of an air bubble curtain to reduce underwater noise levels in the vicinity of pile driving activity was in 6-8 m water depths off the western coast of Hong Kong. The bubble screen (produced using a perforated rubber hose) was developed to reduce noise exposure to resident dolphins. In this application, the bubble curtain was found to have effectively lowered pile driving sound levels by 3- 5 dB up to 1 km away from the source, particularly in the 400-800 Hz frequency range (Wursig *et al.* 2000). While the results of other operations have seen variable success, recent advances in air bubble curtain technology have in several cases led to demonstrated noise reductions in the field of up to 30 dB (Reyff 2004). In general, however, an effective air bubble curtain system is expected to reduce pile driving sound levels by about 10 dB (Hammar *et al.* 2010; Stokes *et al.* 2010), enough to significantly mitigate a number of detrimental effects to biota (Hammar *et al.* 2010; see also Fig. 4 in Nienhuis and Dunlop 2011).

In the Hong Kong example, the relatively shallow depth of the water proved critical to enhancing the sound attenuation success of the unconfined air bubble curtain system. That is, in order for this type of apparatus to create an effective noise barrier, the curtain or screen of air bubbles has to extend from the foot of the pile all the way to the water surface without any holes or gaps. This has proven difficult to achieve in very deep or turbulent water with strong waves or currents, which is often characteristic of offshore locations in the Great Lakes. As a result, unconfined air bubble systems might not be the most effective means of reducing sound transmission during the installation of monopile foundations in many areas of the Great Lakes. Developers involved in the construction of monopile turbines off the Scottish coast had investigated the use of air bubble curtains as a noise mitigation strategy, but deemed their installation infeasible at the site where depths reached 42 meters (Bailey *et al.* 2010). In Germany, however, an unconfined air bubble curtain was employed during pile driving

operations at the FINO 3 offshore wind research platform, where the water depth was approximately 25 m (Matuschek & Betke 2009). To compensate for bubble drift due to currents, the bubble ring was installed at an extended radius of 70 m around the pile. While this measure resulted in sound pressure level reductions of 7-12 dB, the degree of attenuation varied with direction indicating that the integrity of the bubble curtain was compromised due to current in some places (Matuschek & Betke 2009). Furthermore, for a bubble ring of this size, with a circumference exceeding hundreds of meters, much higher-capacity air compressors, energy supplies and related equipment would be needed (Nehls *et al.* 2007).

Multistage air bubble curtains – The complication of greater depth and current speeds was encountered during pile installation by the California Department of Transportation, where local conditions rendered existing unconfined air curtain systems ineffective. As a result, engineers developed several solutions to overcome these challenges, including the use of either confined or multistage air bubble curtains. Multistage air bubble curtains involve a vertically stacked array of perforated rings placed around the pile at different depths. Although the bubbles are still subject to horizontal movement from currents, the idea here is that the ring above would generate additional bubbles, in this way ensuring that a uniform curtain of air bubbles is maintained around the pile. While more effective than the original air bubble curtain design in deeper waters, this type of apparatus would still be limited to currents less than 1 knot (Christopherson & Wilson 2002).

Confined air bubble curtains – In areas with currents or tidal forces exceeding 1 knot, the use of confined or enclosed air bubble curtains would likely be required. For smaller piles, a large, hollow cylinder placed around the pile with the air bubble ring placed within it is an effective means of preventing currents from sweeping the bubbles away, while still ensuring sound attenuation. However, for larger piles, specially manufactured confined air curtain systems might be required. For example, during the pile installation demonstration project for the San Francisco-Oakland Bay Bridge, a thick fabric mantle was constructed to confine the air bubble curtain, resulting in increased sound attenuation over the unconfined system (Illingworth & Rodkin Inc. 2001). Another existing model is the Gunderboom® Sound Attenuation System, comprised of two layers of fabric between which air is bubbled. While this proprietary system has proven highly effective at attenuating pile driving noise in the field in up to 3-knot currents,

the high cost of this alternative might be prohibitive for some developers (PND Engineering 2005).

Although confined air bubble curtain systems have been successfully applied in harbour works where local wave and current conditions are relatively benign, it remains to be seen whether these options would be viable for offshore pile driving where conditions are generally harsher. The use of air bubble curtains to attenuate pile driving sound during offshore wind power project installation in the marine environment has thus far been limited. However, the success of the air bubble curtain system during pile driving at the FINO 3 offshore wind research platform in the North Sea indicates that this strategy should be further explored, field-tested and considered for use in other offshore wind development projects—including those proposed within the Great Lakes. Owing to the performance limitations of current bubble curtain technologies, project sites that are at depths of less than 25 m would be best suited to this approach. As this will likely be the depth range of most Great Lakes projects, air curtain systems have the potential to be used during pile driving operations for turbine installation within the Great Lakes. Recognizing that improvements continue to be made to enclosed air bubble curtain technologies, it has recently been acknowledged that they could be soon be applicable for pile driving in deeper water (Bailey *et al.* 2010).

Isolation casings and cofferdams – Other devices that exploit the density differential between air and water to decouple sound wave transmission from a hammered pile to the surrounding water column are isolation casings and cofferdams. Isolation casings are often hollow cylindrical piles slightly larger in diameter than the pile being driven, which are temporarily installed and dewatered to create an air space around the monopile. Isolation piles were used during construction of the Benicia Bridge in California, and successfully reduced sound pressure levels by 20-25 dB (Illingworth & Rodkin Inc. 2001). Alternatively, to isolate larger piles or project areas from the water column, cofferdams can be temporarily constructed around the work site (Fig. 2). These are commonly fabricated from sheet piling, and like isolation casings are most effective when the water inside is pumped out leaving a large air space between the exposed pile and the water column. In both cases, the sound waves emanating from the hammered pile would have to pass through the air space before reaching the surrounding water, which interferes with sound propagation.

Although both methods are effective at reducing sound levels from pile driving, providing at least as great a sound reduction as air bubble curtains (Caltrans 2009), the larger air space created by cofferdams gives these devices greater sound attenuation value than the smaller isolation casings. Cofferdams have been used extensively during piling works for the San Francisco Bay bridge with good success in reducing potentially injurious sound levels, although site depths were generally less than 15 m. Depending on the additional effort required to install and dewater these temporary structures, particularly for projects with large numbers of individual monopiles or in greater depths, this option might not be well suited for use during offshore wind turbine installation. Here again field-testing under specific site conditions would be required to assess the feasibility and effectiveness of such devices in the Great Lakes.

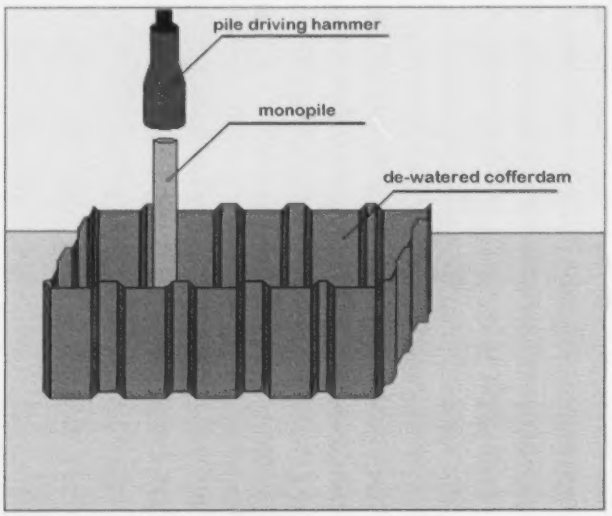


Figure 2. Cofferdam concept. Cofferdams constructed of sheet piling can be temporarily installed around larger piles or project areas to isolate pile driving sound waves from the water column, reducing the noise injury potential to fish. De-watered cofferdams achieve greater sound pressure level reductions owing to the difference in sound wave propagation between air and water.

Reducing noise levels at the source

As discussed above, mitigation options to reduce the effects of pile driving noise on fish include warning or deterrence techniques to keep fish away from the zone of impact, or devices to reduce the propagation of sound pulses into the water column to minimize the zone of impact. They also

include less noisy methods of pile installation or devices that reduce sound levels directly at the pile driving source.

Vibropiling – A technique of vibropiling has recently emerged as an effective means of reducing the noise levels associated with pile driving in the aquatic environment. In this case vibratory hammers rather than impact hammers are used to deliver light, rapid beats to the pile to make it vibrate. These vibrations cause the surrounding sediment at the base to liquefy, allowing the pile to sink in. Vibratory hammers produce sound energy that is generally 10 to 20 dB lower than impact hammers, although the accumulated sound exposure level from vibropiling could be higher because this technique requires considerably more time to install the pile (Caltrans 2009). The reduced sound pressure levels generated by vibropiling might also reduce impacts on nearby fish. For example, caged brown trout held in the field as close as 25 m to the source were found to elicit no behavioural reactions to vibropiling activity (Nedwell *et al.* 2003), indicating that this method could minimize effects to certain fish species.

Unfortunately, vibropiling is only suited for small or medium-sized piles, specific substrate types, and relatively shallow depths. In addition, impact pile driving is still required initially in order to "proof" the piles and test their load bearing capacity. As a result, while it should still be considered as an option in appropriate field conditions, vibropiling might need further development before it is a viable option for noise mitigation during offshore pile driving. Where vibropiling is not feasible, pre-drilling or water-jetting in the piles could help to attenuate some of the noise generated during impact pile driving by loosening the substrate and allowing the pile to be driven further with each blow (PND Engineering 2005). In this way the number of strikes required to install a pile could potentially be reduced, thereby reducing the temporal extent of hydroacoustic impacts. However, these options have yet to be employed extensively in offshore construction projects, and could act to further increase turbidity at the pile driving site, and thereby impact fish in other ways.

Press-in piling – Another technique that could replace conventional impact pile driving is the use of a press-in piling machine. These are self-contained devices that use static forces i.e. the leverage of a previously installed pile, to install the monopiles. Because no impulsive type noises are created using this technique, underwater sound levels are expected to be significantly less

than those resulting from impact pile driving. For this reason, press-in piling has been the preferred method for pile installation in highly sensitive areas such as where human hearing concerns exist, or during critical biological periods like turtle migrations (Spence *et al.* 2007). While these machines had conventionally been used on land or in shallow water and required that consecutive piles be located adjacent to one another, they can now also be mounted on a barge or other structures to allow for pile installation in deeper waters. In addition, it is also possible to install the initial pile (used as leverage to press in subsequent piles) using this machine, avoiding the need for potentially harmful impact methods. Unfortunately, the current technology only allows for the installation of piles up to 1.5 m in diameter (Spence *et al.* 2007), which is smaller than what is required for monopile turbine foundations. However, it could be a recommended alternative for tripod foundations which use smaller piles.

Noise damping devices – Solid materials or devices with good acoustic impedance properties can be used to dampen the noise from the pile driving source more directly. In some cases, the use of cushion blocks with impact hammer pile drivers is a sound attenuating option. By placing a block of material that deadens sound transmission on top of a steel pile, the resulting noise levels generated during hammering can be reduced. Blocks of wood have been shown to reduce source sound pressure levels by 11-26 dB, while blocks of nylon and micarta can achieve sound pressure reductions anywhere from 4-8 dB (Washington Department of Transportation 2006). Wood silencer blocks are effective at reducing higher frequency wave lengths, but the lower frequencies that are more harmful to fish might not be as effectively minimized (PND Engineering 2005). Cushion blocks have typically been used for projects with smaller piles, and could require the use of larger hammers with greater energy to counteract the reduced efficiency of the hammer due to the block, which reduces pile driving efficiency. In addition, the durability and practicality of using cushion blocks for repeated and prolonged pile driving activities would need to be considered by project engineers. For example, while wooden blocks achieve greater noise reduction than synthetic materials, they tend to rapidly disintegrate or catch fire when repeatedly hammered (Laughlin 2006). Despite this, the advantage of cushion blocks is that they can easily be used in conjunction with other sound mitigation systems, such as bubble curtains or cofferdams, to achieve additive noise reduction.

Alternatively, noise emanating from the pile can be dampened by insulating the monopiles with different types of solid materials that exploit the sound impedance mismatch between the barrier material and water. Recent field experiments showed that while a 6-mm rubber sleeve placed around a pile was inefficient at reducing sound pressure levels, a 20-mm layer of foam wrapped around a steel tube carrier and slid down over the pile significantly reduced underwater sound by 10-20 dB, though only for frequencies above 500 Hz (Nehls *et al.* 2007). Additionally, air-filled sleeves that could be installed around a monopile in up to 25 m depths have been proposed for offshore wind turbine pile driving, and design models estimate that these could reduce noise levels at lower frequencies by about 20 dB (Nehls *et al.* 2007). However, the weight required as ballast to compensate for the buoyancy of this air-sleeve system could make installation and removal difficult (Matuschek & Betke 2009). It is feasible that insulation with other types of materials could further minimize the transmission of low-frequency sounds during offshore pile driving activities, though efficient and economically viable solutions have yet to be developed.

Noise mitigation during other construction activities

Machinery noise

In addition to pile driving, there are a number of other noise producing activities that take place during offshore wind turbine installation that could cause additive disturbance to nearby aquatic organisms. Construction machinery such as onboard compressors or generators, for example, can be extremely noisy and transmit significant low-frequency sound energy into the water if placed directly on steel hulls. In order to partially reduce the transmission of sound from these sources, placing noisy equipment on tires, rubber or foam mats as an acoustic decoupling strategy has been proposed (Jefferson *et al.* 2009), and employed (Wursig *et al.* 2000) as a noise mitigation technique during offshore construction in the marine environment. This is a rather simple solution to minimizing potentially disruptive sounds from onboard construction machinery and could be easily adopted by developers in the offshore wind industry. Additionally, the simple practice of turning off construction machinery when not in use can further reduce the exposure of aquatic organisms to noise.

Reducing disturbance from boat noise

Increased vessel traffic to and from the wind power project site during construction will also add to the anthropogenic noise levels in the area. Boat noise alone is commonly linked to behavioural

avoidance in fish and other aquatic organisms (e.g. Gerlotto & Freon 1992, Misund *et al.* 1996), but in conjunction with other noises from construction it could potentially have more significant, cumulative effects on animals. The sound levels produced by motor-powered vessels typically increases with ship size, while the frequency of the emitted sound tends to decrease with increasing vessel size (Richardson *et al.* 1995). As a result, the low-frequency engine noise from large barges and freighters could pose a greater risk to nearby fish than the running noise produced by smaller boats. Very large vessels will necessarily be required to transport the large turbine components and assembly equipment such as cranes and pile drivers to the project site. While this cannot be avoided, there are some options that might reduce the impacts associated with large vessel traffic.

The working components of all construction-related vessels should be routinely inspected and serviced to ensure that they are in good repair and running efficiently, as this can help to cut down on running noise. Propellers and thrusters contribute the most to underwater noise levels, so regular maintenance of these components is particularly important (Spence *et al.* 2007). These parts can also be modified or designed to further reduce noise levels, although the costs of doing so is often non-trivial. An alternative option is for larger vessels to be towed to the project sites by smaller ships or tug boats that produce less harmful low-frequency sound levels, or to moor large vessels once they are in place so that thrusters aren't needed for dynamic positioning. In addition, because boat noise increases with increasing speed, vessel operators travelling to and from wind power project sites could limit their running speeds to minimize noise disturbance—particularly in sensitive habitat areas (Evans 2003). Vessels used for wind turbine construction could also be routed along pre-specified transportation corridors that avoid areas known to house critical fish habitat or species of concern. This precautionary approach was employed during construction of both the Horns Rev and Nysted wind power projects, where all transport and construction vessels were routed around nearby nature protection areas (Kjaer *et al.* 2006). Similar recommendations or requirements could be proposed for proponents involved in offshore wind development in the Great Lakes to avoid unnecessary disturbance to areas of ecological significance or fish species of conservation concern.

Dredging noise

Unlike monopile foundation installation, gravity base foundations do not require noisy pile-driving operations, and for this reason might be preferable from a noise-reduction perspective. However, extensive sediment dredging and levelling is often required to prepare the lake bed for gravity base foundation installation, and these activities could still generate a significant amount of low-frequency underwater noise. While dredging noise has not been the focus of many environmental impact studies to date, it might be plausible that devices otherwise employed to mitigate dredging-related increases in turbidity—such as air bubble screens or cofferdams (see below) –could also function to reduce noise levels. However, to our knowledge there have been no attempts made to measure or document the potential of these devices to attenuate noise specific to dredging operations. The choice of dredging equipment can also affect the noise levels generated during these operations. Suction hopper dredges create significantly more sound than mechanical or bucket dredges owing to the noise produced by the powerful onboard pumps and generators required to vacuum up the sediment (Spence *et al.* 2007). Sounds associated with bucket dredges include noise from winches and derrick movement and from the bucket striking and digging the sediment, which are not necessarily high impact sound sources. Thus, if dredging noise is a concern in certain areas, mechanical dredges might be the preferred option although factors like sediment type, efficiency of removal, and turbidity levels would need to be considered as well.

Noise from geophysical survey activities required for site selection

Another wind power project-related activity recently flagged for underwater noise concerns is the geophysical or geotechnical assessment required for site characterization during the pre-construction phase (Nedwell & Howell 2004). These surveys are typically conducted using seismic techniques or boomers and sparkers, both of which can produce significant amounts of noise. Ramp-up or slow start methods similar to those proposed to warn mobile species of pile driving operations could be adapted to reduce the potential for injury associated with these activities as well. This mitigation strategy is already recommended in guidelines for exploratory air-gun seismic surveys in marine offshore areas (Canada-Newfoundland and Labrador Offshore Petroleum Board 2008). However, it would be best for developers to limit the use of these high-

impact sound pressure level survey techniques and instead employ less harmful alternatives such as hydroacoustic methods to measure and characterize the lake bottom wherever possible.

2.3 Measures to control operational noise

Even though activities during the construction phase are projected to generate the most harmful noise levels of any offshore wind power project activity, the high impact noise will be limited to relatively short time periods (from weeks to over a year). On the other hand, while it is characterized by much lower sound pressure levels, operational noise will impact the underwater soundscape continuously for decades. The low-frequency sound levels produced by the rotating blades and structural vibrations are not loud enough to harm or injure fish directly. Concerns exist, however, because operational noise is detectable above ambient noise levels and therefore has the potential to mask biologically important sounds and alter fish communication and behaviour. Measures to reduce operational noise from offshore turbines are mostly related to engineering or acoustic design standards, which will certainly continue to improve in the future. For example, because much of the noise generated by operational wind turbines is derived from the moving parts within the gearbox, some novel turbine designs now include direct driven generators that eliminate the need for a gearbox altogether (Hammar *et al.* 2010). These designs however, have yet to be employed in offshore projects.

It is generally the case that broadband noise increases with increasing rotational speed of the turbine blades. Accordingly, the use of variable speed turbines or pitched blades to control or lower rotational speed in high winds is one existing option to reduce noise levels from turbulence (World Bank Group 2007). Foundation type has also been shown to influence the efficiency of sound transmission from mechanical noise, with concrete gravity foundations radiating lower frequency sounds than steel monopile foundations (Hammar *et al.* 2010), although the magnitude of sound emitted appears to be similar between monopile and gravity foundations. Because some fish species might be more disturbed or have their vocalizations masked to a greater degree by lower frequency sounds, this could mean that monopile turbine foundations would be preferable from an operational noise mitigation perspective. Finally, another alternative could be to employ noise or vibration minimizing materials to acoustically insulate the gearbox housing, below-water tower surfaces and/or foundations, in this way reducing sound transmission into the water column. By inserting a layer of material such as a foamed polymer between the tower and the

water, the emitted operational noise could be reduced significantly (Ingemansson Technology AB 2003).

2.4 Mitigating impacts from electromagnetic fields

The generation of electromagnetic fields (EMFs) from the extensive network of inter-array and power transmission cables associated with offshore wind power projects could also affect certain Great Lakes fish. Although there remains a great deal of uncertainty regarding the potential impacts from EMFs, there is reason to believe that these fields could alter behaviour and distribution of some fish species. Furthermore, unlike most other offshore wind power project effects, the area potentially impacted by EMFs would not only exist within the network of cabling connecting turbines to each other and to offshore substations, but would also extend into shallow-water and coastal environments through which transmission cables will run to carry electricity ashore. The recognition that EMFs could impact migratory or other types of behaviour in electro- or magneto-sensitive fish has prompted investigation into a number of strategies that could be employed to reduce or mitigate some of these potential effects.

Cable burial

The most common precautionary recommendation to reduce EMF effects on local fauna, which has been put into practice for a number of marine wind power installations, is to bury the cabling in the sediment to a depth of at least 1 m (Linley *et al.* 2007). Though it may seem surprising, physical modelling studies have demonstrated that burial in non-magnetic sediment is actually ineffective at dampening the magnetic fields emitted by a power cable (CMACS 2003). However, the magnetic field is at its maximum at the cable surface and will decay with increasing distance from the cable (Gill *et al.* 2009). As a result, cable burial to a depth of 1 m is still likely to reduce the exposure of electromagnetically sensitive fish to the strongest magnetic and induced electric fields that exist within millimetres of the cable, owing to the physical barrier to contact created by the sediment. Burial to depths greater than the suggested 1 m is unlikely to produce any additional EMF mitigation benefits (CMACS 2003). That is, it would not be practical to achieve the burial depth required to reduce the magnitude of the magnetic and induced electric fields enough so that they are below detection for certain fish species (Department of Energy and Climate Change 2009; Gill *et al.* 2009). Unfortunately, although cable burial has been considered an effective method of mitigation for EMF exposure, trenching

is not always feasible in hard or rocky substrates. In this case, the use of armour stone, concrete mattresses, or other materials might be placed on top of the cables. While armouring is likely to be required as a measure to protect unburied cabling from ice scour or damage from anchors or fishing gear anyways, it is unknown whether these materials would have the added benefit of reducing EMF exposure to fish or not.

Cable design

The electromagnetic properties of the materials used in manufacturing submarine power cables can also affect the strength of the resultant EMFs. It has been shown through electrical engineering models that as the permeability of cable armouring material increases, the EMF strength outside the cable decreases. Steel tape for example, having an order of magnitude greater permeability than steel wire (King & Halfter 1982), would therefore be the preferred armour material from an EMF-reducing point of view, although the material strength of each alternative would also need to be considered in cable design (CMACS 2003). In addition, cable sheathing or armouring materials that have higher conductivity values can also help to reduce the strength of the emitted EMFs, as can thicker sheathing or the use of double-wire armouring (CMACS 2003). According to a recent report, a technique of core twisting can also substantially reduce the magnetic field in proximity to the cable (Ohman *et al.* 2007). Despite their theoretical or demonstrated effectiveness at reducing EMFs, these material properties and cable designs could all substantially increase the cost of production or make cable laying more difficult and therefore expensive.

Future advances in the field of electrical engineering might provide improved options for reduced EMF-emitting offshore wind cable design. The cable system to be used for the Cape Wind Energy Project, which will likely represent the first offshore wind power facility in North America, is a three-core solid dielectric AC cable design with grounded metallic shielding to block and contain any electric fields (U.S. Department of the Interior 2009). Developers state that this type of cabling was chosen specifically to minimize any EMF effects. However, although current industry design standards for AC cables effectively shield against direct electric field emissions (U.S. Department of Energy 2009), they cannot completely shield the magnetic component and therefore still produce induced electric fields (Gill 2005).

Other considerations

It should be noted here that much uncertainty remains regarding the potential for EMFs from submarine cables to affect fish behaviour in the Great Lakes. Additional research will be required in order to fully understand the potential effects of EMFs on local fish species, and until then it is difficult to assess the benefit of these different mitigation strategies weighed against their potential financial or other environmental costs. One example to consider here is the trade-off between reducing exposure strengths of EMFs through cable burial and the potential disturbance to benthic habitats that would result from dredging or water jetting to dig the cable trenches. With regards to its mandate to protect fish and fish habitat, Fisheries and Oceans Canada recommends the placement of submarine power cables on top of freshwater lake beds as a more favorable option to burial within the substrate, as the former generates less disturbance and suspended sediment than the latter (Fisheries and Oceans Canada 2010b). DFO does not, however, have any specified recommendations for EMF exposure from power cables. In the end, it might be determined that dredging and turbidity pose a greater threat to freshwater fish species than potential EMF effects, which could preclude the need for burial as an EMF reducing strategy. Clearly, a better understanding of what these effects might be is needed. It is worth noting that even if EMF exposure is not found to pose a high risk to fish, burial within the sediment or under concrete mattresses or rip-rap material might still be necessary in order to protect the cable from damage due to ice scour, anchors or entanglement with fishing gear.

2.5 Mitigating dredging and sediment disturbance

Minimizing disturbance during cable laying

In order to minimize lakebed disturbance and suspended sediment release during underwater cable installation in the Great Lakes, it has been recommended that a single-operation process be employed (Great Lakes Wind Collaborative 2009) whereby the trenches are excavated and the cables are laid and buried simultaneously. This would minimize the need for multiple types of machinery and re-occurring disturbance to the benthic environment. The use of hydraulic jet ploughing technology is considered to be the least environmentally disturbing option for cable installation in offshore environments (World Bank Group 2007). The jetting device minimizes bottom disturbance by hydraulically fluidizing a narrow trench of sediment into which the guided cable settles to the required depth. Because dredging is not required, this process

suspends only a relatively small amount of sediment into the water column which rapidly resettles on top of the cable (U.S. Army Corps of Engineers 2005).

Fisheries and Oceans Canada recommends that cables be placed on top of the lake bed rather than using unconfined open trench methods to bury the cables in the substrate, as the former generates less sediment and avoids the need for machinery in the water (Fisheries and Oceans Canada 2010b). However, if cable burial is necessary for Great Lakes wind power projects either as an EMF mitigation measure or to protect the cabling from ice scour or other damage, then hydraulic jet ploughing technology could represent the least damaging alternative compared to traditional open trench technologies.

Because nearshore and shoreline environments are often critical fish habitat areas supporting high species diversity or containing spawning habitat, and are typically dynamic in terms of wave and current action, care must be exercised when running submarine cabling though these areas. Not only should disturbance to these habitats be minimized, but possible damage to the cables from shoreline waves and winter ice scour must also be avoided. Horizontal directional drilling (HDD) is commonly used for pipeline or cable installation in such cases in order to avoid disturbances from dredging or excavation in littoral or shoreline areas, and to protect cables from damage in dynamic environments (Fisheries and Oceans Canada 2010c; Hanson *et al.* 2003). The boring commences at an upland site, where a pilot borehole is drilled horizontally well below the lakebed of the nearshore area, emerging in the water beyond the environmentally sensitive zone where the cable is then pulled back up through the hole (Fig. 3). In this way, disturbance to nearshore aquatic habitats and species are minimized.

Horizontal directional drilling is not without its risks however, including the possibility for vertical fractures or tunnel collapses called "frac-outs" which could result in the escape of drilling muds or fluids into the aquatic environment. For this reason, vigilant monitoring is required during the process, and emergency frac-out responses and contingency plans need to be put in place (Fisheries and Oceans Canada 2010c). In addition, the proper disposal of excess drilling muds, drill cuttings and other wastes is critical. Finally, at the termination point of the bore hole, drilling activity could cause significant local increases in suspended sediment mixed with drilling muds or slurries. In order to mitigate this disturbance, cofferdams could be placed

temporarily around the HDD borehole end transition to contain the sediment re-suspended during excavation. This is the proposed mitigation strategy for the Cape Wind Energy Project, which proponents claim will be sufficient to minimize turbidity-related impacts to sensitive species (U.S. Department of the Interior 2009).

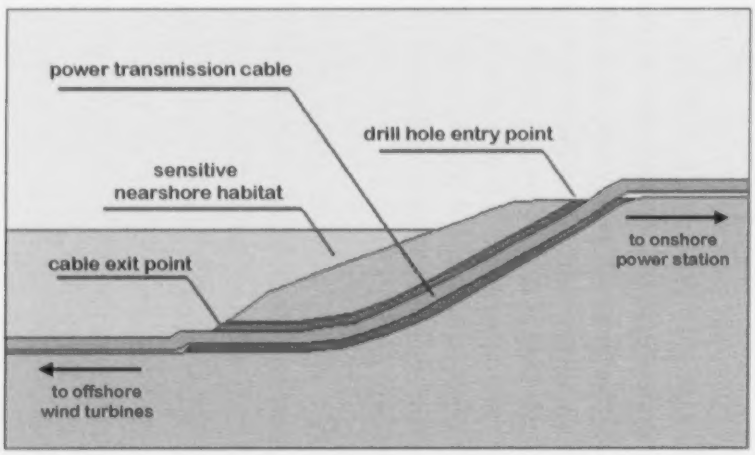


Figure 3. Horizontal directional drilling concept. To avoid disturbance to sensitive nearshore or shoreline habitats from dredging or trenching, submarine power transmission cables can be run through holes drilled well below the lakebed before connecting to onshore power stations.

Reducing impacts from dredging operations

The installation of gravity-base foundations requires a pre-levelled lake bed, which in most cases will necessitate the need for dredging in preparation for foundation laying. Thus, in areas where disturbance to sensitive habitats or species from dredging activities would be unacceptable, it might be preferable to install monopile foundations rather than gravity base foundations to minimize these effects (Hammar *et al.* 2010; World Bank Group 2007). On the other hand, monopile installation creates other types of disturbance, especially from loud pile driving activities, and these tradeoffs need to be considered in the selection of foundation type.

If gravity base foundations are to be installed, the choice of dredging equipment can have a significant impact on the amount of sediment released during these operations, and therefore on the degree of disturbance to local fish and fish habitat. Mechanical dredging techniques such as clamshell or bucket dredges typically result in much greater suspended sediment and turbidity than hydraulic dredges like suction hoppers or cutterheads (Johnson *et al.* 2008). The former tend

to spill sediment out through the tops and sides of the bucket when contact with the bottom is made, during withdrawal through the water column, and upon breaking the water surface. Modifications can however be made to reduce sediment spill or loss during mechanical dredging. The use of watertight rubber seals along the bucket edges of a clamshell dredge, or the incorporation of multiple overlapping plates to create closed systems, for example, has been shown to generate significantly less turbidity in the water column during fine-grained sediment dredging than typical buckets would (Herbich & Brahme 1991). While these closed or "environmental" bucket systems might be useful in smaller project areas, hydraulic dredges would be preferable to avoid elevated levels of fine-grained particles in the water column. One caveat here is that the excavated sediment-water slurry removed during hydraulic dredging should be well contained on the barge or hopper, and not be allowed to overflow into the water column (Palermo *et al.* 2008).

Options for turbidity control

Where dredging operations are necessary, it is best for these activities to be performed during periods of low wind and wave energy to minimize the spread of resulting turbidity plumes. In addition, there are several devices which have been used to contain the spread of suspended sediment and thereby limit the area impacted by increased turbidity. Although the use of cofferdams was mentioned above, and could be effective for certain applications, perhaps the most commonly recommended practice to mitigate impacts from turbidity during in-water construction projects is the use of silt curtains or turbidity barriers (Hanson *et al.* 2003; Jefferson *et al.* 2009; Johnson *et al.* 2008). These are temporary, flexible floating curtains that are anchored to the bottom around the work area, and comprised of either an impervious reinforced thermoplastic material or a semi-permeable geosynthetic fabric (Fig. 4). Silt curtains create a barrier or enclosure allowing fine-grained suspended sediment to settle out and be diverted under the curtain.

Where they are feasible for use, silt curtains can control the spread of near-surface turbid water in the vicinity of dredging operations, and minimize the dispersion of fine-grained sediment in the upper water column outside the silt curtain (Herbich & Brahme 1991). Unfortunately, the effectiveness of silt screens is significantly limited in project locations with high currents, wind speeds or waves, as these conditions can cause the curtain to move, tear or leak (Palermo *et al.*

2008; Stryker *et al.* 2009). Furthermore, proper installation of silt curtains can often be quite difficult and labour intensive (Erftemeijer & Lewis 2006), and continuous monitoring and maintenance is necessary to ensure barrier integrity. Thus, unless dredging operations will be taking place in quiet bays or on very calm days, the use of silt curtains as a mitigation measure during offshore wind turbine installation in the Great Lakes might not be a very useful option.

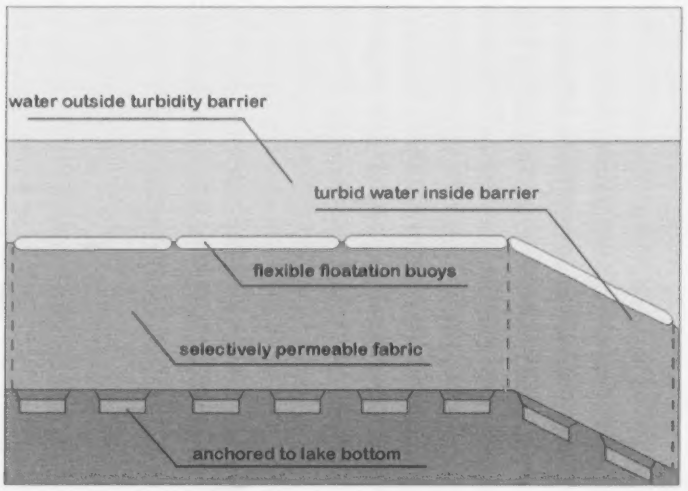


Figure 4. Silt curtain or turbidity barrier concept. Silt curtains are often deployed to contain the spread of suspended sediment or turbidity plumes arising from in-water construction or dredging operations. These are flexible floating curtains comprised of impervious or semi-permeable material that are anchored to the bottom around the work area creating a barrier for turbidity.

In addition to silt curtains, air bubble curtains could also be used for turbidity control during dredging operations. This method has been used successfully to control suspended sediment released during a sediment remediation project in the Kinnickinnic River, which flows into Lake Michigan (Stryker *et al.* 2009). In the former instance, a perforated pipe blowing compressed air was laid across the river channel creating a wall or curtain of bubbles which caused suspended solids to fall out of the water column. This bubble curtain was shown to have quantitatively reduced suspended sediment levels downstream, and was deemed a successful turbidity mitigation measure for this application. Unfortunately, it is not clear whether this type of system would work in deeper project locations where the action of waves and currents could compromise the integrity of the bubble screen (as indicated above for noise reduction). Despite current technical challenges, the use of air curtains to control turbidity during offshore dredging

projects should be further investigated, as they could have the added benefit of reducing noise levels or acting as fish deterrents.

Mitigation options to address the alteration of sediment transport

The increase in current velocity and change in water flow that occurs around below-water turbine components alters local sediment transport dynamics, resulting in scour and substrate loss around the foundation and subsequent redistribution of fine sediments further away. Scour protection materials placed around the turbine base are used to prevent the formation of scour pits and stabilize the structure, although changes in sediment erosion and deposition patterns through what is known as secondary scour is still possible even with these materials in place (Rees *et al.* 2006). The effects of altered sediment transport might be reduced by streamlining component shapes, or by reducing their size and surface area (U.S. Department of Energy 2009). Cumulative impacts on sediment transport and potential far-field effects from multiple turbines can be minimized by increasing the spacing between turbine units or altering their orientation (Meißner & Sordyl 2006). Exercising precaution in site selection so as to avoid placing turbines in or near shoreline areas with particular sensitivity to altered coastal or sediment dynamics such as sandy shoals or beaches is also recommended to reduce detrimental impacts to benthic habitats from wind turbine-related changes in sediment transport.

2.6 Minimizing habitat loss

Another potential impact of offshore wind power projects is habitat loss or destruction. The immediate area of benthic habitat to be covered by the turbine foundations and scour protecting materials will necessarily be destroyed. However, the physical area occupied by the turbine structures themselves is generally less than 1% of the total area of a wind power project, so the loss of habitat due to foundation placement is not that significant. Aside from opting for smaller footprint foundation types like monopiles as opposed to the larger gravity base foundations, there is very little that can be done to avoid this rather minimal loss of benthic habitat. If project sites are selected so as to avoid sensitive or critical habitat areas (e.g. spawning shoals), the loss of benthic habitat resulting from foundation installation should have minimal impact on local fish species.

Habitat loss or destruction could also occur during the sediment dredging activities which are required to level the substrate for gravity base foundation installation and for cable laying. As

discussed above, the use of horizontal directional drilling to minimize impacts to shallow-water and shoreline habitats from cable crossings, and the use of jet ploughing technology to lay and bury the cables are recommended to reduce the extent of damage to benthic habitats.

2.7 Reducing the potential for water quality degradation

There are several ways in which the construction and operation of offshore wind power projects could negatively impact local water quality (Nienhuis & Dunlop 2011). Of primary concern is the potential release of sediment-bound contaminants during dredging and drilling activities. While silt curtains or other types of turbidity barriers could help to reduce the spread of disturbed and potentially contaminated sediments (Palermo *et al.* 2008), the most effective way to reduce the risk of remobilizing harmful contaminants during construction activities is to simply avoid installing turbines or cables in areas with unacceptable levels of persistent organic pollutants or heavy metals. Through the Great Lakes Water Quality Agreement, the US and Canadian governments have identified Areas of Concern where sediment contamination is so great as to require dredging restrictions for the protection of aquatic organisms and human health (Krantzberg & Montgomery 2007). Furthermore, outside of these designated areas there are additional sites within the Great Lakes where sediment contaminant levels exceed provincial standards or guidelines. Areas such as these with high sediment contaminant levels should be considered as areas to avoid turbine installation. Sediment sampling surveys and associated chemical analyses, bioassessments and toxicity testing procedures are relatively straightforward to conduct (Palermo *et al.* 2008), and an option is to include them as part of the site selection process.

In addition to contaminant release from dredged sediment, water quality issues associated with the evolution and discharge of drill cuttings and other associated waste products could arise during horizontal direction drilling activities or if monopile installation requires partial drilling. To reduce potential adverse effects of drill cuttings, it is recommended that construction crews use water-based drilling fluids as opposed to synthetic- or oil-based muds to lubricate the drill bit, as the latter have been identified as potential sources of hydrocarbon and other contaminant release and toxicity (OSPAR Commission 2009).

There are additional potential risks associated with offshore wind power projects that could have consequences for local water quality. First, wind turbines represent potential collision hazards for vessels (Biehl & Lehmann 2006) and although such collisions are unlikely, they could impact the local aquatic environment if shipboard wastes, oils or fuels are subsequently released. Secondly, hydraulic or other operating fluids could leak from damaged turbine units or be accidentally discharged during routine maintenance or servicing. To avoid or prevent these types of accidents, operators could take measures such as enforcing vessel speed limits in the vicinity of turbines, ensuring that all personnel are well-trained, and prepare spill control and response plans. In marine offshore wind power projects, common practice to avoid boat collision includes restricting vessel traffic (e.g. for fishing) around the base of turbine towers.

2.8 Avoiding negative impacts from invasive species

Wind turbine foundations and scour protection structures will likely provide ideal habitat for several invasive species including dreissenid mussels and round gobies. While it might prove difficult to control the spread of these species in the Great Lakes, proponents should be cognizant of the fact that wind turbines could create stepping stones for their further range expansion. As far as reducing the potential for invasive species to spread to new areas of the Great Lakes, knowledge of their current distributions will help to guide preventative site selection for wind power projects. For example, care could be taken to avoid placing high densities of wind turbines in potential corridors for the range expansion of these species, such as along the boundaries of their current range limits.

Although it is important to recognize that offshore turbines will in all likelihood provide ideal habitat for several invasive species, the overall magnitude of effect is uncertain at this point. The effect could range from minimal (especially given the small surface area of wind turbine structures), to more severe if projects are located in corridors of possible range expansion. It might also be possible that the colonization of turbine foundations by non-native species could negate the habitat creation benefits, if the presence of these non-native species negatively effects local fish populations or deters fish from utilizing the new habitats for spawning or foraging; more research is needed to evaluate this possibility.

2.9 Options to reduce conflicts with Great Lakes fisheries

Vessel collision risks and the potential for gear entanglement owing to the presence of offshore wind turbines, scour protection materials and submarine cabling could interfere with local recreational or commercial fisheries in the Great Lakes. While cable burial is commonly recommended to reduce the potential for fishing gear entanglement, the major issue here will be if conflicts over loss of access to fishing grounds arise. Loss of access will occur where wind power projects overlap with commercial fishing activity and if fishing vessels in those overlapping areas are restricted from accessing fishing grounds at the base of wind turbines. In Canadian waters, there is commercial fishing activity in each of the Great Lakes, with some areas being more heavily utilized than others (Kinnunen 2003). The same is true also for recreational fisheries in the Great Lakes. Lake Erie produces the most valuable commercial fisheries (for yellow perch and walleye) in Ontario waters and being that it is also one of the lakes most suitable from a wind energy perspective, is where the greatest potential for loss of access conflict could arise.

Similar concerns certainly exist for marine wind power projects, and from the experiences there it seems that considerate spatial planning is often the best solution to prevent these types of conflicts (e.g. Berkenhagen *et al.* 2010). In many cases it might be advisable for offshore wind power developers in the Great Lakes to consult with representatives of local commercial, recreational or First Nations fisheries during the site-selection phase to discuss plans for project location, size and layout. In the U.K., the British Wind Energy Association also encourages developers to employ and have a representative from the local fishing community on board during cable laying or other activities to offer advice that could minimize disturbance to fishing activities (BWEA 2004). Active engagement of local resource users can help to promote a mutual understanding between interest groups, and can reduce potential conflicts by helping proponents to identify and avoid locating projects in or around popular or traditional fishing grounds. During the site-selection phase for the Cape Wind Energy Project, for example, a number of proposed sites were relocated to avoid impacts to mobile gear fisherman who had identified the initial sites as areas where they frequently fished (U.S. Department of the Interior 2009). To further limit conflicts with recreational or commercial fishers, another option would be to implement timing windows during key fishing seasons, for example, to limit disturbance from construction noise.

2.10 Considerations for decommissioning

When the 20-25 year operational phase of a wind power installation comes to an end, the project would then be decommissioned. Exactly what the decommissioning phase will entail remains unclear at this point, although it will likely involve either the partial or complete removal of the turbines, foundations and power transmission cables. In the future, decommissioning might also include replacement of turbines, but as far as we are aware this is not a current reality. The decision to remove all of the submerged structures will likely be dependant upon whether or not the foundations and scour-protecting materials have created habitat and are used by native fish species for foraging or spawning, and whether disturbance to these new habitats is acceptable. Regardless, most of the activities associated with decommissioning will probably be similar to those that occur during construction. Increased vessel traffic, noise from machinery and cutting tools, increased turbidity from sediment disturbance, and the potential for high-impact noise if explosives are required to remove entire foundations are all possible types of disturbance that could arise. Options for mitigating the negative effects of these activities would therefore be similar to those identified for construction activities.

As part of Ontario's Renewable Energy Approvals (REA) Regulation, developers proposing to engage in renewable energy projects are required to submit a decommissioning plan report describing procedures for dismantling or demolishing the facility, activities related to the restoration of any land and water negatively affected by the facility and procedures for managing excess materials and waste (Ontario Ministry of the Environment 2010). Other jurisdictions have also required that developers submitting proposals for offshore wind developments include a decommissioning scheme for their installations and associated electric lines, and some require that developers provide up-front arrangements to ensure that funding to carry out the proposed scheme is available when the time comes (Department for Trade & Industry 2004). The Ontario Ministry of the Environment similarly retains the ability to require financial assurance on any project issued a REA (Ontario Ministry of the Environment 2010). However, because new and more appropriate technologies and mitigation options could well be developed in the decades between approval and the end-of-life phase of the project, any decommissioning plan would need to be periodically reviewed and have the flexibility to respond to changes in circumstance that might arise.

3. Enhancing benefits

As has been demonstrated in marine systems, and as we highlighted in our first report (Nienhuis and Dunlop 2011), offshore wind power projects could potentially benefit fish and fish habitat in a variety of ways. A summary of the potential benefits and examples of how these benefits might be enhanced within the Great Lakes is found in Table 2. Here we focus on options to enhance the habitat creation potential of offshore wind turbine structures, as there has been a great deal of study related to artificial reefs and habitat enhancement strategies upon which to draw. Furthermore, the potential for wind power projects to enhance recreational fisheries will be largely dependant upon whether they serve to attract aggregations of sport fish, which will depend on artificial reef design as well. Much less is known of the potential for wind power projects to increase the biomass of certain species by serving as sanctuaries from fishing activity; we include a few possible options for enhancing this benefit in Table 2, but do not discuss it further in this section.

3.1 Enhancing the habitat creation potential

Ideally, wind turbine foundations and scour protection materials (Fig. 5) could act as artificial reefs and enhance spawning and recruitment success for native Great Lakes fish. Defining the measures necessary to achieve this end, however, is not straightforward. There are numerous studies which indicate that an artificial reef can successfully enhance the abundance of certain fish species when: constructed in appropriate locations with the right materials; developed with specific and clearly defined management goals in mind; and designed with biological expertise. While the mechanism driving increased concentrations of fish at artificial structures remains unclear and is most often attributed to attraction and redistribution of stocks from other areas, there is some evidence to suggest that artificial reefs could also increase fish production by providing additional habitat resources. It is uncertain whether or not turbine foundations and scour protection mounds at offshore wind power installations could act as artificial reefs and enhance production for native fish species in the Great Lakes. Recommendations to enhance spawning or foraging habitat for fish through foundation design, appropriate selection of scour protection materials and turbine layout may be guided by the experience of other habitat or fishery enhancement projects. However, because of the uncertainty that exists, it is inappropriate to be prescriptive here. Rather, we shall review the findings of previous studies on artificial reefs

and spawning habitat enhancement efforts in the Great Lakes to highlight suggestions that could be relevant to promoting fish habitat creation around offshore wind power installations.

Of the recently constructed artificial reefs in the Great Lakes that have been deemed successful from a fish attraction point-of-view, many are comprised of single long or multiple parallel piles of concrete or rock rubble that extend more than 200 m in length and in most cases run parallel to shore. The majority of these are located roughly 1-3 km from shore and in waters typically between 5-10 m in depth. In contrast, most offshore wind turbines will likely be constructed further from shore and at depths greater than 10 m (depending on the lake), and have scour protection mounds encircling the foundations with radii extending no more than 10-25 m (Fig. 5) out from the turbine base (Baker 2003; Wilson & Elliott 2009). In addition, turbines will have to be spaced anywhere from 500 m to 1 km or more apart within wind turbine arrays, meaning that any interconnectivity between the scour protection piles might be difficult to achieve. Because of these fundamental differences in location, design, and size, it is challenging to directly translate the experience of existing artificial reefs in the Great Lakes into recommendations for scour protection design at offshore wind power installations.

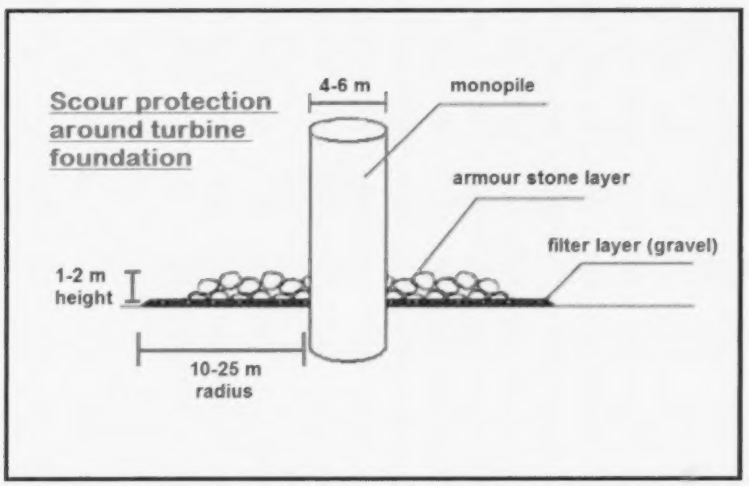


Figure 5. Diagram of typical scour protection mound placed around turbine foundations. Depending upon the size, height, shape, slope and type of material used, these structures could act as incidental artificial reefs and attract or create habitat for fish.

Table 2. Strategies and examples for enhancing benefits of offshore wind power projects to fish and fish habitat in the Great Lakes. This table follows a similar structure to Table 1 in the first report outlining potential effects (Nienhuis & Dunlop 2011).

Effect	Associated wind power activity	Predicted magnitude of effect without enhancement (uncertainty)	Enhancement strategy	Examples of specific enhancement options	Potential limitations for use in the Great Lakes
Habitat creation (enhanced foraging, refuge from predators, spawning habitat)	Physical presence of structures	Medium (High)	• Choose appropriate shapes, sizes and connectivity of scour protection mounds	• Enhance structural complexity by increasing height of scour protection mounds. Increased connectivity among scour protection mounds will promote habitat creation potential for some species	• Knowledge gaps exist as to species preferences for habitat. Larger areas of scour protection might attract higher densities of non-native species
			• Choose specific scour protection materials or foundation designs that promote use or spawning by target species	• Use appropriately sized rocks/cobble if lake trout spawning is desired	• Degree to which other wind power project activities will deter or impact fish not known
			• Optimize turbine configuration, size of project, and project location	• Steep slopes adjacent to scour protection mounds can promote use by lake trout	• Typical turbine spacing (0.5-1 km) makes connecting mounds difficult
Protection of fish from commercial fishing in and around turbines and cables could increase fish biomass as in a sanctuary or marine protected area	Operation	Low (High)	• Implement time window restrictions for enhanced protection of fish during critical periods	• Protection during spawning time	• Conflicts might arise with commercial and recreational fishers denied access to fishing
			• Increase size of protected area	• Extend protection to entire wind power project area	
Enhanced recreational fishing opportunities (through the artificial reef/fish aggregating effect)	Physical presence of structures	Low (High)	• Provide opportunities for anglers	• Allow access to turbine towers and foundations and/or surrounding areas	• Increased risk of vessel collision and potential fishing gear entanglement with scour protection material or submarine cabling
			• As for habitat creation, choose specific scour protection materials and design that promote use by target species	• Increase vertical relief, heterogeneity of substrate sizes and shapes	

Interestingly, while many artificial reefs in the Great Lakes have been constructed with specific habitat restoration or fishery enhancement goals in mind, nearshore man-made structures that have been installed for other purposes (including water intake structures, breakwaters, jetties and other shoreline modifications) have recently been shown to act as incidental artificial reefs in that they can also attract significant numbers of fish species (Gannon 1990). Because they could also serve as incidental reefs, this finding could hold relevance to turbine foundation design. There has been a good deal of research in recent years to understand and characterize the attributes of critical habitats for various fish species and populations in the Great Lakes. In particular, a lot of research has been driven by ongoing efforts to re-establish spawning lake trout populations throughout the Great Lakes. The study of spawning success and fish abundance at artificial reefs and other man-made structures, in conjunction with assessments of natural spawning shoals, has been integral to our current understanding of how best to implement habitat restoration for lake trout and other fish species. The body of knowledge gained through these studies could also be useful to guide habitat enhancement efforts at offshore wind power installations. Thus, despite obvious differences in location, size and intended purpose, there are several aspects to reef design that emerge from these examples which could offer insight for offshore wind proponents interested in creating attractive fish habitat.

Enhancing structural complexity to promote fish use

Whether they are built in marine or freshwater ecosystems, it is generally the case that fish attraction to artificial structures increases with increasing reef volume, size, surface area, and structural complexity (Keller *et al.* 2006; Wills *et al.* 2004). Unless individual rock piles are purposely interconnected or extended with additional material, the size of the scour protection mounds around turbine foundations could be significantly smaller than reefs designed and built intentionally for habitat enhancement. Regardless, there might still be options to maximize surface area and structural complexity at these installations. For example, building up the height of the scour protection mounds could enhance their attractiveness for certain fish species. At the Olcott artificial reef in southwestern Lake Ontario, the presence of vertical relief and a variety of rock sizes (including boulders greater than 1 m in diameter) were factors believed to have attracted rock bass in a relatively short time after installation (Gannon *et al.* 1985). Many artificial reefs in the Great Lakes are more than 2 m in height, which probably contributes to their success in attracting fish by creating a visual stimulus as well as the vertical relief sought

after by many species. Based on existing designs, it has also been recommended that reef planners ensure heterogeneity in the width and height of artificial structures. This was found to be a critical factor in attracting the greatest diversity of percids and centrarchids to an artificial reef in southwestern Lake Michigan near Chicago, Illinois, as certain species have been shown to exhibit preference for the highest peaks, while others the lower valleys and edges of artificial reef structures (Creque *et al.* 2006).

In addition to building up the height and vertical relief of the structure, incorporating a range of substrate sizes and shapes to increase both micro- and macro-habitat complexity also appears to be an important design criteria for developing functional artificial reefs (Gannon *et al.* 1985). By providing heterogeneous microhabitats, the use of a variety of material sizes can help to enhance benthic productivity and increase the forage base for fish at artificial structures (Gannon 1990; Gannon *et al.* 1985). A range of substrate sizes also increases the heterogeneity of interstitial spaces available as refuges from predators as well as for egg incubation, among other things. For this reason, the size and number of interstitial spaces can also influence which species, ages, and size-groups are attracted to the artificial structures, as well as predator-prey interactions (Bolding *et al.* 2004). In general, the depth of substrate and the resulting depth of interstices tend to be greater at man-made structures than at natural spawning reefs. Because deeper interstices can protect eggs from washout, this factor could be an important contributor to reports of enhanced egg survival at artificial structures, especially for species like lake trout (Fitzsimons 1996). As far as the choice of materials for scour protection, naturally occurring materials (such as quarried rock or limestone), materials that won't degrade or leach harmful substances into the water, and materials that retain long-term physical integrity are preferable (Brown 2005; Gannon 1990).

The slope of scour protection mounds can also be designed to enhance fish attraction and spawning habitat. Artificial structures with steeper slopes or gradients have been found to lead to higher concentrations of fish, and have resulted in increased angler success for bluegill and crappie, as one example (Bolding *et al.* 2004). Building rocky mounds with steeper slopes also has the advantage of increasing the depth range covered by the artificial structure with less material required. Assessments of artificial reefs in the Great Lakes have demonstrated that lake trout spawning is often most successful on steep-sided reefs with slopes of 30 - 45° (Fitzsimons 1996). It is not entirely clear why slope is so important in these cases, although the gradient of a

structure can influence its interaction with and subsequent strength of local hydrodynamic forces (Fitzsimons 1996). In this respect, it has also become clear that current and wave action over nearshore rocky substrates in the Great Lakes can strongly influence the biological communities found in these habitats (Gannon *et al.* 1985), with certain fouling organisms and fish species preferring more high-energy environments and others requiring calmer waters.

For incubating lake trout eggs, exposure to currents is often a critical factor; sufficient currents are required to keep interstices clear of sediment infilling which can suffocate eggs, while excessive exposure to currents might result in significant mortality due to the shock sensitivity of developing embryos, (Fitzsimons 1996; Marsden *et al.* 1995), although shock sensitivity appears to be lake- or stock- specific (Fitzsimons 1994). This might explain why in Lake Superior and Lake Huron, artificial reefs found to have good lake trout spawning success have been located in protected areas where wave and current action is somewhat reduced (Fitzsimons 1996). However, more recent work suggests that so long as they remain in place and are not washed out by current action, lake trout eggs can be quite robust in the face of strong currents (Fitzsimons *in review*). Having an understanding of both the variation in sensitivity among stocks or species to current forces, and the local current regimes likely to arise around artificial structures could prove to be important to successful artificial reef design.

Turbine configuration

While the layout of offshore wind turbine arrays is typically designed to maximize wind energy capture, spacing to enhance habitat use from a biological perspective could also be considered (Linley *et al.* 2007). There is evidence that the installation of artificial reefs in a fractal pattern maximizes habitat complexity and biological productivity (Lan *et al.* 2004). Furthermore, it has been suggested that clumped reefs are preferred to dispersed reefs (Lindberg *et al.* 1990). In addition to layout, the spacing of turbines will also be important for attracting various fish species. Based on assessments of different artificial reef patterns in the marine environment, it appears that in order for groupings of multiple smaller reefs to effectively enhance fish abundance, they should neither be placed too closely together nor too far apart (De Alessi 1996). For this reason, assuming standard offshore wind turbine spacing for installations at the Cape Wind Energy Project, proponents conducting environmental assessments anticipate only very minor impacts on fish species composition from the habitat created by turbine foundations and

scour protection (U.S. Department of the Interior 2009). It remains to be seen whether this will also be the case for offshore wind power project installations in the Great Lakes.

The potential for efficiency losses owing to the wake effect arising from multiple turbines necessitates the rather large (0.5-1 km) minimum spacing requirements between turbines. As a result, the spacing of the multiple "mini-reefs" within wind power project areas cannot realistically be decreased. However, it would be possible for proponents to either increase the radius of scour protecting materials around individual turbines, or to build additional mounds in between foundations in order to enhance the connectivity and spatial heterogeneity of these structures, if doing so is preferable from a habitat enhancement perspective. Worth considering here is that if burial of submarine power cables is required (e.g. to reduce EMFs or prevent ice scour damage or fishing gear entanglement), the placement of concrete or rock rubble material on top of the cables as opposed to burial within the sediment could increase the amount of available habitat for fish. For inter-turbine cables this could provide a means of connecting the individual reefs around each foundation together. For the power transmission cable running to shore this option could create what is essentially a long artificial reef along the cable trace, which would have a much greater surface area or footprint of available habitat than individual scour protection mounds. However, the success of this option will depend on whether the desired species are deterred or impacted by the EMFs themselves.

Species-specific habitat preferences or requirements

The fact that all fish species have evolved optimal physiological tolerance ranges to factors like temperature and dissolved oxygen concentrations is a critical aspect of fish ecology which dictates geographical ranges as well as within-lake distributions. For this reason, it is important to consider placement depth, upwelling patterns, and seasonal changes in temperature and water quality factors when selecting sites for artificial habitat structures (Gannon *et al.* 1985; Mathews 1985). A significant issue that arises in freshwater ecosystems is the possible development of anaerobic conditions below the thermocline in summer months. Placing structures in deeper water where this is likely to occur could limit the use of artificial habitat by fish species that are intolerant to low-oxygen conditions. For example, reefs intended to attract centrarchid species should be placed in nearshore areas that are less susceptible to upwelling and the development of thermoclines in order to ensure consistent warm water temperatures throughout summer.

Previous experiences within the Great Lakes have demonstrated that artificial reefs located in 4 - 7.5 m of water are ideal for many centrarchid species including bass, bluegill and crappie (Creque *et al.* 2006; Lynch & Johnson 1988). Conversely, artificial reefs that are situated further offshore are susceptible to unstable thermal habitats making them unsuitable as habitat for these species (Creque *et al.* 2006). To keep warm water fish concentrated around a reef complex even when thermal stratification occurs in deeper areas, it has been suggested that artificial structures could be placed in rows that extend from shallow to deeper water so that fish can move into shallower or more oxygenated waters as necessary (Bolding *et al.* 2004). These examples demonstrate that knowledge of local and seasonal conditions, as well as an understanding of the physiological tolerances of target fish species to different temperature or dissolved oxygen conditions will be essential in selecting suitable sites for artificial habitat enhancement projects.

Artificial structures generally work best to concentrate bottom and structure-oriented species, territorial species, or obligate reef spawners. Through monitoring studies of nearshore artificial structures, Great Lakes fish species that have been found to be attracted to habitat modifications that include riprap, steel piling, concrete or rock rubble, cobble and other materials include walleye, mottled sculpins, yellow perch, smallmouth bass, rock bass, largemouth bass, lake trout, lake whitefish, spottail shiner, white sucker, white crappie and round gobies, among others (Bolding *et al.* 2004; Fitzsimons 1996; Herdendorf 1985; Jude & DeBoe 1996; Rutherford *et al.* 2004). In contrast, structure in nearshore environments doesn't usually drive the presence of open-water or pelagic species like salmonids, for example. Clearly, prior knowledge of which fish species exist within the system and are likely to inhabit or utilize specific project areas is necessary in order to ensure greater chances of success in attracting fish to the artificial structures (Wills *et al.* 2004). Similarly, an understanding of the specific life history and habitat requirements of possible inhabitants will be important in the selection of appropriate scour protection material type, size and design, as well as in the design or layout, and location of turbine arrays.

Lake trout habitat restoration

Because there has been a lot of emphasis in recent years to restore spawning populations of lake trout throughout the Great Lakes, and because offshore wind turbine foundations and scour protection materials might be located in areas suitable for lake trout spawning habitat, it is worth

highlighting some of the critical habitat requirements for this particular species. Lake trout require coarse, cobble-like substrate with interstitial spaces for successful spawning and egg incubation. Ideal substrates are angular to subangular in shape (Fitzsimons 1995), with sizes ranging between 10-20 cm (Fitzsimons 1996). Substrates smaller than this are more prone to sediment infilling, which should be avoided as lake trout require clean substrate clear of fouling or fine sediment in order to incubate their eggs (Marsden *et al.* 1995; Rutherford *et al.* 2004). For this reason, locating artificial lake trout spawning habitat in areas surrounded by fine or sandy substrates might not be ideal in some areas as currents could sweep these sediments onto incubating eggs. Having a significant influence on the movement of sediments, lakebed relief and local current regimes around a reef could play a more critical role in dictating the integrity of reef spawning sites than the nature of the surrounding sediment, however.

While many historical lake trout spawning shoals were located on offshore reefs at a variety of water depths (Fitzsimons 1996), current populations of stocked lake trout appear to spawn primarily on shallow, nearshore reefs (<16 m) (Marsden & Chotkowski 2001). In Lake Michigan, for example, artificial structures with evidence of lake trout spawning have included areas 3.5 -11 m in depth while in Lake Huron and Lake Superior, good artificial lake trout spawning reefs have been documented in depths of 3- 10 m (Fitzsimons 1996). Other design factors that characterize good artificial spawning or egg-fry habitat for lake trout include having minimum reef heights of 1-2 m (Edsall & Kennedy 1995; Fitzsimons 1996), ensuring steep enough slopes (up to 45°) adjacent to spawning sites to provide access to deep water for juveniles (Marsden *et al.* 1995; Rutherford *et al.* 2004), and having more elongate as opposed to square reef shapes or configurations (Fitzsimons 1996). Finally, it should be noted that lake trout tend to spawn in a home range that often only extends within a 60 km radius of their stocking site (Fitzsimons 1996), which has additional implications for the location of habitat enhancement projects.

It has recently become apparent that lake trout are attracted to artificial structures, as indicated by the fact that eggs and fry have been collected on numerous man-made structures like breakwaters and intake lines. In some cases, these structures have even been relatively small (some less than 1000 m^2) (Fitzsimons 1996). Consequently, there is a possibility that lake trout could use the rocky scour protection mounds around turbine foundations as spawning habitat. As part of recent

lake trout management plans in the Great Lakes, it has been recommended that candidate areas for stocking efforts have numerous closely aggregated reefs with suitable habitat (Bronte *et al.* 2007), which could well characterize wind turbine scour protection "reefs" if they are properly designed and laid out. For these reasons, it might be worth designing these structures with lake trout habitat restoration in mind, using the available knowledge regarding habitat requirements and preferences for this species. However, significant uncertainty exists as to the extent that other disturbances from wind power projects (e.g. from noise or EMFs) will deter lake trout from utilizing turbine foundations as habitat; more research is certainly needed on this topic.

4. Baseline monitoring

Baseline monitoring is important because it serves three critical purposes: (1) providing information on which effects are expected or of significance for a particular wind power project area; (2) determining if there are any important or sensitive species, life stages, or habitat present in the area; and (3) providing baseline information to serve as a reference against which to detect potential effects caused by the wind power project. This information can subsequently help to guide any specific mitigation measures that might be necessary for a particular wind power project. These purposes are described in more detail below.

Having a clear understanding of the spatial and temporal variability in fish abundance and habitat use, and the local physical, chemical and biological processes that characterize a proposed project area can help proponents to identify which effects of wind turbine installation are possible and need to be considered within the project area. This will in turn facilitate more quantitative risk assessments and subsequently guide appropriate mitigation actions. For example, if it is determined through pre-construction habitat assessment surveys that the proposed project area includes critical habitat for fish species of economic importance or of conservation concern, the risk associated with habitat destruction or disturbance from noise or dredging during construction would be increased. Accordingly, decisions would have to be made as to whether some of the mitigation strategies identified earlier in this report could be employed to reduce the risk to acceptable levels, or whether project relocation is necessary.

Baseline surveys can also help wind power project developers identify areas that contain highly contaminated sediments where the risk of contaminant remobilization and the potential for biotic uptake resulting from dredging activities could be substantial. Similarly, pre-construction fish community surveys can provide information about if and when EMF-sensitive fish species (e.g. in the Great Lakes this would include American eel and lake sturgeon) inhabit the project area. Because they are at a greater risk from EMF effects than other fish, seasonal use of the area by such species could dictate the need to alter submarine cable routes. Another example is the use of the area by particularly sensitive life stages (e.g. fish eggs and larvae); the presence of these life stages could indicate the need to implement construction timing windows to reduce exposure to harmful noise and reduce disturbance or harm from dredging activities. These examples demonstrate the role that baseline monitoring and site characterization can play in assessing the site-specific risks of different wind power related activities, and how this can help to guide appropriate harm reduction measures. That is, activities that are projected through baseline assessments to pose high risk owing to site-specific habitat or species sensitivities will likely require directed mitigation measures or could even necessitate project relocation. In contrast, the expense and effort of implementing specific mitigation measures might not be justified in areas where corresponding activities are expected to pose very little risk to fish or fish habitat.

A second, and related, purpose of baseline monitoring is to determine if any key species or critical/regulated habitat are present in the wind power project area that would trigger certain legislative or required mitigative action. For example, if the proposed project site includes fish or other organisms listed under the Endangered Species Act or the Species at Risk Act, or their habitat, the project will likely require consideration of a variety of mitigation and avoidance measures. Species at Risk (SAR) distribution maps (Conservation Ontario 2010) and available information on the critical/regulated habitat of listed species could readily be consulted (see Appendix A for a list of available information) to help identify and avoid areas where these sensitive species might be found (Ministry of Transportation of Ontario 2009). While this information can provide initial guidance, site-specific fish community monitoring surveys will ultimately be needed in order to confirm the presence or absence of a species of conservation concern within the proposed action area. In a recent document, Fisheries and Oceans Canada details the protocol for the detection of fish species at risk in Ontario Great Lakes (Portt *et al.*

2008) (see Appendix B). Baseline habitat assessments and fish surveys that identify the presence of important species or habitat and describe fish abundance and habitat use can therefore help proponents to establish which sites would be acceptable for development from an environmental risk management point of view, and which might not be.

Finally, in order to be able to detect and quantify the degree of impact that specific wind power project related effects might have on fish or fish habitat, baseline data collection is recommended to describe existing conditions before development activities are initiated. In this way, control conditions can be established to serve as a reference against which any future change brought about as a result of wind power project construction and operation can be detected and measured. By defining reference conditions, the collection of baseline data will also enable developers to evaluate the degree of success or failure of different harm-reduction or benefit-enhancing measures that are implemented for different projects.

4.1 Spatial and temporal considerations

Identifying the appropriate spatial scale across which to conduct baseline monitoring for offshore wind power projects will be very important. In general, the size of the assessment area should correspond to that of the proposed project area, and should be sufficient in extent to enable later quantification of potential direct, indirect, and potential cumulative impacts of the project. At the very least it should encompass the entire area within which the turbines will be arrayed as well as along the planned cable route (these two components comprise the "wind power project area"). However, because some of the potential impacts of offshore wind power projects are projected to propagate beyond the project area (e.g. see Table 1 in Nienhuis & Dunlop (2011)), and because of the uncertainty associated with the extent of various direct, indirect, or potential cumulative impacts, it might be prudent to extend the pre-construction monitoring area beyond the outer perimeter of the wind turbine array.

In addition to spatial scale considerations, the timing and frequency of site survey activities is equally important to consider. The specific habitat requirements of different species of fish tend to vary throughout their life cycles. Quite often, what might be ideal habitat for egg incubation differs from preferred juvenile nursery grounds, which in turn are often different from the habitat requirements of feeding or spawning adults. As a result, individual species rarely remain within a

given lake habitat across seasons or life history stages. For this reason, in order to fully characterize fish use within a given project area, multiple-season sampling is necessary. That is, surveys of fish abundance and habitat use should be conducted at least once during each season in order to establish a representative sampling of the species likely to inhabit the project area throughout different times of the year.

Prior to construction, seasonal sampling over multiple years is needed in order to account for the natural annual variations in fish abundance and distribution patterns that could result in atypical monitoring results or the failure to detect future changes in fish populations. Through statistical power analysis, Lester *et al.* (1996) estimated that for a set of lakes in Ontario sampled with a standardized nearshore netting protocol, a minimum of 7 years of pre- and post-impact monitoring would be required to detect a two-fold change in fish abundance. Thus, in order to reliably detect the effects of offshore wind power projects on fish abundance, baseline monitoring over several years would be needed at proposed sites. In the very least, three years of pre-construction, baseline monitoring over multiple seasons would be the minimum advisable from a science perspective.

Just as fish undergo seasonal migrations or changes in habitat use, many species also elicit diel movement patterns, occupying different depth strata or habitat types throughout the day or night. Examples of Great Lakes fish that move diurnally between shallow and deeper-water habitats include the pelagic coregonids (Hrabik *et al.* 2006) and several species of shiner (e.g. spottail and mimic shiners) (Scott & Crossman 1973). Some Great Lakes species (such as freshwater drum and many catfish) are nocturnal, and emerge to feed at night, while other species or life history stages are more active during the day (e.g. yellow perch); some may even be most active at dawn and dusk. Here again, sampling design is important to consider in order that local fish communities within the project area are accurately represented. For this reason, both daytime and night time surveys, and/or surveys that capture the crepuscular period, would be important components of a multi-year, seasonal baseline monitoring programme. Finally, it will be important that baseline monitoring studies target both benthic and pelagic fish species spanning all size classes and life history stages to fully capture the habitat requirements and use by fish within the project area. Science-based options and defensible methods for fish surveys that take

into account these criteria for baseline monitoring are discussed in a later section on post-construction monitoring.

4.2 Fundamental data requirements

The unique character of individual project areas will define the nature of the fish communities likely to be found within them, such that different sites could be inhabited by different species assemblages. Site-specific fish community inventories are therefore necessary in order to confirm fish use of an area, define the general fish community structure, and provide information regarding potential specialized use of the area such as for spawning, nursery grounds or migratory corridors (Ministry of Transportation of Ontario 2009). In addition, baseline surveys will allow developers to identify whether the area is used by species of particular economic importance, species with specific habitat requirements, or species of conservation concern (i.e. SAR). This information is critical as the presence of such species will have implications for mitigation strategies, as discussed above.

As they are already required for other development activities, some form of habitat assessment would likely be an important component of any offshore wind power project as well. For example, in the case of highway development activities or other transportation projects that could impact fish or fish habitat, documentation of existing habitat types within the proposed project area is a requirement for baseline monitoring (e.g. see Ministry of Transportation of Ontario (2009)). Habitat assessments involve describing and mapping the unique physical, chemical and biological features and attributes of the area. In order to identify (and thereby mitigate if possible) whether a wind power project will alter critical habitat, such as spawning habitat for a key species like lake trout, it would be advisable to describe lake-bottom conditions throughout the project area prior to construction. This would include mapping the physical features of bottom morphology (i.e. identifying the presence and frequency of rocky reefs, outcroppings or shoals etc.) as well as sediment composition, geochemical properties, and particle size distribution. To fully document site-specific conditions for fish and habitat, benthic invertebrate and plant community assessment will also be needed.

Hydrographic data describing the direction and velocity of currents, as well as water quality data including temperature, salinity, and dissolved oxygen should also be collected when establishing

baseline site characteristics. In addition, information regarding the frequency and duration of thermal or chemical stratification and the depth of summer thermoclines will be important, and could help to guide habitat enhancement designs as discussed earlier.

When conducted appropriately, habitat assessments can help characterize the fish community likely to inhabit an area. Thus, if habitat assessments are undertaken as part of preliminary site investigations, findings could inform decisions regarding the suitability of the site for development before more time-consuming fish community surveys are undertaken. Furthermore, prior knowledge of the fish species likely to inhabit the area can guide the selection of appropriate fish community sampling techniques. Preliminary assessments aside, it is recommended that habitat monitoring surveys be conducted concurrently with fish community surveys as part of the overall baseline monitoring strategy. By linking fish observations to specific habitat features, concurrent habitat assessments and fish surveys can provide insight into the habitat requirements of different species which will be important to assessing impacts (Ministry of Transportation of Ontario 2009).

4.3 Towards a standardized approach

Emphasis must be placed on ensuring that all baseline data are collected using defensible methods that follow existing provincial, national and international scientific standards and protocols for particular survey types. Furthermore, monitoring studies need to be well-designed in order to provide meaningful results with sufficient levels of confidence (Michel *et al.* 2007). It is also recommended that individuals conducting the surveys have adequate and demonstrable qualifications and expertise in the area of study (BSH 2007). These guidelines will help to ensure that the data collected are statistically valid and useful for detecting effects so that the time, money and effort spent conducting baseline surveys is not wasted (CEFAS 2004). In addition, a standardized approach to data collection could facilitate comparison between sites and provide broad scale regional overviews of offshore wind power project impacts to fish and fish habitat in the Great Lakes. It would also aid in being eventually able to quantify potential cumulative effects.

Provided that investigators employ standardized and spatially and temporally consistent habitat assessment and fish survey methods, the results of pre-construction phase monitoring surveys

can serve as a baseline for comparison with the results of construction, post-construction and operational phase monitoring. In this way the overall effects of different phases of offshore wind power project development on habitat resources and fish abundance and distribution within the project area can be assessed.

4.4 Establishing control or reference sites

While control or reference sites are important in impact studies in order to test cause-effect hypotheses, and are integral to Before-After-Control-Impact (BACI) –type experiments, it is often difficult to find or select such sites in the field. Ideally, reference sites should be identical, or as similar to impacted sites as possible, comprising the same biotic and abiotic elements as the project area under investigation (BSH 2007). In most cases this would mean selecting areas adjacent to or otherwise close to the project area. However, in order to be true "controls" these sites must be outside the area of impact for the particular effect under investigation. For example, studies of fishery resources at Horns Rev, Denmark, revealed that fish were attracted to the wind power development from more than 500 m away. As a result, reference sites to assess the impact of offshore wind installations on fish abundance and distribution had to be located further than 500 m away from the project area (Michel *et al.* 2007). For assessments of the impact of pile driving noise on fish behaviour and movement, the control or reference sites will have to be even further away—up to tens of kilometres from the project area—in order to be outside the detection distance of certain species (Thompson *et al.* 2010). In cases like this, it might prove difficult to find ecologically and physically comparable sites to serve as controls, which could necessitate the need to develop alternative experimental and sampling designs to detect and measure specific effects.

5. Options for effects monitoring

Projections of the potential effects of offshore wind power projects on Great Lakes fish and fish habitat are based largely upon reported effects from offshore wind projects in the marine environment and other comparable development projects previously undertaken in the Great Lakes and elsewhere. In order to enhance our understanding of the relative impact that different wind power project related effects will have on Great Lakes fish and habitat resources, project-specific impact assessments and effect monitoring are required. As identified in Nienhuis and

Dunlop (2011), the construction and operation of wind turbine installations could have a number of negative impacts on local fish species or fish habitat, as well as several potential benefits. Although some of these effects can be predicted with greater certainty (including the probable impacts of pile-driving noise on nearby fish and the extent of habitat loss that will result from turbine foundation installation) many will be much harder to predict. For example, our understanding of the potential effects of EMFs from submarine cabling or turbine operational noise on fish distribution and behaviour, or of the ability of wind turbine foundation and scour protecting materials to create new spawning or foraging habitat for native fish species suffers from a great deal of uncertainty.

For the most part, knowledge on the extent or importance of the effects of these novel offshore installations on specific Great Lakes fish and habitat will only come about through directed on-site monitoring studies. Through effect monitoring studies, proponents can better quantify the risk associated with different wind power project related activities and in this way design and implement appropriate mitigation plans. In addition, monitoring studies will be a necessary aspect of adaptive management programs in order to test the adequacy of different mitigation measures and guide the development of more effective alternatives as required. In this section we review some of the guiding principles for good monitoring design, review common experimental approaches to impact assessment, and describe several examples of specific effect monitoring studies that have been conducted for wind power projects in the marine environment and that could be adapted for projects in the Great Lakes.

5.1 Duration of post-construction monitoring

Some of the impacts to fish and fish habitat that are projected to arise from wind turbine installations will be manifested over the short-term, while others will have longer lasting effects. Monitoring studies designed to assess the impact of specific activities or different phases in the life-cycle of wind power projects will have to consider the temporal scale over which effects are likely to be experienced. For example, impact studies to determine the effect of construction noise or dredging-related sediment disturbance on resident fish species and benthic habitats will need to involve intense, focussed sampling throughout the periods immediately preceding, during and following the activity giving rise to the particular effect under investigation. Conversely, longer-term but potentially less intensive monitoring studies would enable the

detection of changes in local invertebrate and fish community assemblages in response to the presence of wind turbine foundations.

The amount of time required for recently disturbed or newly developing ecological communities to undergo succession and reach a state of biological equilibrium can be substantial, especially in north temperate freshwater ecosystems. For example, based on long-term studies of succession at artificial reefs in marine systems, it has been estimated that the time frame required to develop a progressed community can be well over a decade, even in tropical ecosystems (Perkol-Finkel & Benayahu 2005). Furthermore, the ability to detect changes in nearshore Great Lakes fish abundance in response to anthropogenic disturbances usually requires many years of sampling prior to and after an impact (Lester *et al.* 1996). Thus, while construction-phase effect monitoring will require more focussed or continuous sampling efforts timed around specific activities, operational phase monitoring, and the ability to detect long-term changes in the distribution and abundance of fish or gradual changes to benthic habitat features or community composition will require that investigators undertake ongoing sampling efforts over multiple years post-construction. For example, in order to systematically test the benefit to fish populations of potential no take areas for fisheries within wind power project areas, or owing to the artificial reef effect that may arise from turbine foundations, it has been noted that monitoring over longer time periods of 5-10 years will be required (Linley *et al.* 2007).

A minimum of three years of post-construction monitoring has been recommended or undertaken for other offshore wind turbine installations (BSH 2007; Kjaer *et al.* 2006; MMS 2009). However, the considerable uncertainty that exists as to effects of offshore wind power projects in the Great Lakes would suggest that some form of monitoring should be maintained throughout the operational lifetime of a project. The three year minimum adopted for wind power projects in marine systems has been inadequate for documenting effects to fish distribution, population dynamics and recruitment, and contributes to the considerable knowledge gaps that remain despite the existence of offshore wind farms in Europe for over a decade. To address this uncertainty, while at the same time recognizing that different effects will manifest over different time scales (i.e. from days to decades), agencies could consider requiring intensive monitoring seasonally for 3-5 years post-construction, but then follow-up by requiring less intensive monitoring at intermittent periods (e.g. every 3-5 years thereafter) for the duration of the project.

5.2 The importance of a standardized approach to monitoring

In general, post-impact monitoring should mirror the seasonal timing, spatial extent, frequency and survey methods of pre-construction or baseline fish community surveys and habitat assessments, as this will facilitate more robust before-and-after comparisons. However, studies attempting to elucidate the effect of specific activities on particular aspects of fish physiology and behaviour or on individual habitat components might require more directed sampling techniques than those employed for broader-scale baseline surveys or habitat assessments. Regardless, appropriate controls or reference sites are generally advisable. As with baseline monitoring, all sampling methods and protocols should follow existing scientific standards, and surveys should be conducted by well-trained and qualified personnel.

5.3 The role of hypothesis testing

In order to ensure that impact studies generate meaningful and scientifically defensible results, monitoring plans need to be designed with a hypothesis-testing, experimental approach in mind. To this end, biometricians or other experts should be consulted when developing sampling plans in order to determine the minimum amount of replication and sampling frequency necessary for changes to be detectable with an acceptable degree of certainty. Selecting an appropriate experimental design to quantify the effect that a particular wind power project activity or component might have on fish or fish habitat is absolutely essential. The most common experimental approaches to monitoring the impacts of different types of anthropogenic disturbance on natural communities or ecosystems are Before-After-Control-Impact (BACI) studies and gradient sampling designs. These sampling designs have been widely employed in environmental impact assessments as they enhance our ability to detect population or ecosystem responses to disturbance or change despite a background of significant natural variability. Examples of where this type of experimental approach has been used to monitor the impact of various offshore development activities are interspersed throughout the following sections.

The choice of experimental approach will depend on the type of effect being studied and the environmental receptor(s) likely to be impacted, as well as upon practical considerations related to the area being studied, the spatial and temporal extent of the anticipated impact, and timing or budgetary constraints. When sufficient pre- and post-construction data within the wind power project area is collected and if appropriate control or reference sites are available, then a BACI-

type study would be favourable as it represents the most statistically robust design (Wind Turbine Guidelines Advisory Committee 2010). However, in instances where the severity of the impact is expected to decrease with increasing distance from the source, or where the potential spatial extent of the effect is uncertain, gradient sampling design often proves more powerful than a BACI design in detecting changes due to anthropogenic disturbances (Ellis & Schneider 1996). In addition, a gradient sampling design has the added advantage of not requiring an arbitrary selection of control or reference sites. As discussed earlier, establishing a control or reference site can be challenging in the field, especially for far-ranging effects which necessitate that the impact and reference areas be located at significant distances from one another where physical and ecological similarities decrease. Finally, the results of a gradient design model are often easier to interpret (Ellis & Schneider 1996), which might make them more useful to proponents or members of the general public interested in reviewing the outcome of wind power project monitoring programmes. Examples of how these experimental designs have been used to detect the impacts of specific wind power project activities or components are reviewed below.

5.4 Monitoring the effects of noise

To evaluate the impact of noise on fish, whether from loud construction activities like pile driving or from operating wind turbines, various types of baseline information will be required. Essential to any study of anthropogenic noise disturbance to fish or other aquatic organisms are measurements of background or ambient noise within the project area and the anticipated area of impact. Underwater sound levels would be recorded prior to the initiation of construction activities, and measured under various seasonal conditions in order to fully characterize the ambient soundscape of the area. These background noise levels will serve as a comparison from which to gauge the relative contribution or significance of novel sound sources to the local acoustic environment.

In addition, it is important to thoroughly characterize the sounds generated during the specific activity of interest (e.g. pile-driving) or produced by operating wind turbines, depending on which phase is being investigated. This will include accurately measuring the acoustic signature of the sound source and the sound pressure levels across the full range of frequencies using appropriate sound measuring devices or equipment. Information on source sound pressure levels, as well as site specific data on water depth and substrate type are necessary to be able to

calculate or model noise transmission loss. These calculations can then be used to evaluate noise attenuation through water and predict the area of hydroacoustic impact for different sound sources. As an example, guidelines for underwater sound measurement techniques and methods to calculate noise transmission loss and area of impact are provided by the California Department of Transportation (Caltrans 2009). Finally, knowledge of the identity of fish species likely to occupy the area (acquired through baseline fish community surveys), and of their sensitivity to sound (which can be measured in the laboratory) will further enhance predictions of noise impacts to fish and can guide necessary mitigation measures.

The gross behavioural response of fish communities to noise during specific construction activities can be evaluated by comparing abundance and distribution within the anticipated area of impact before, during and after the activity of interest. The effect of operational noise on fish behaviour, however, will be more challenging to elucidate given the potential confounding effect of other impacts such as EMFs or habitat creation that could also result in avoidance or attraction. One option to evade this issue might be to conduct parallel measurements of sound levels and fish abundance within the project area under different wind speeds (i.e. sound levels) as well as during any periods of temporary turbine shut downs. This approach would remove at least some of the other confounding effects, but might not permit disentangling the effects of EMFs.

On the subject of noise monitoring, it is also important to evaluate the effectiveness of any noise mitigation measures employed. Measurements of sound pressure levels generated by the activity in question both with and without the selected noise attenuation measures put in place would enable direct evaluation of whether harmful noise levels have indeed been reduced as intended. Additionally, focused studies designed to assess the ability of different noise attenuating devices to reduce harm or injury to fish, or to minimize behavioural disturbances would be extremely valuable. Here again, these types of studies might involve measuring a specific response (i.e. mortality or tissue damage in caged fish, or catch rates of fish within the impact area) both with and without, or with varying degrees of sound attenuation employed. In this way, if it is discovered that the mitigation measure creates no substantial reduction in sound levels or resulting impacts to fish, improved alternatives can be developed and put in place.

5.5 Assessing the potential impacts of electromagnetic fields on fish

The potential impacts of EMFs from submarine power cables on fish behaviour and physiology are poorly understood, especially in a Great Lakes setting. In order to fully understand or predict the effect that emissions from submarine turbine cables will have on aquatic species, a valuable piece of information is the nature and strength of the electric and magnetic fields associated with the specific type of electrical transmission cabling to be employed at a given offshore wind power installation. While electrical engineering models can be used to simulate or predict field strengths and their attenuation with distance from the cabling, direct EMF measurements should ideally be made in the field at varying distances from the cable, and across the full range of voltages and amperages expected to be carried by the cables across their operational lifetime, and as additional turbine units come online (U.S. Department of Energy 2009). Measurements should be conducted not only along the length of the cable running to shore (where burial might occur to greater depths in some areas and alter EMF strength) but also within the inter-turbine array. It has recently been recognized that significant EMF interaction can occur between cables lying within close proximity to each other within an offshore wind power project, such as would occur at offshore substation connection points (Gill *et al.* 2005). The potential for additive effects from overlapping EMFs is difficult to predict based on modelling alone and would need to be analyzed through site-specific measurements of the resultant field strengths of multiple closely arrayed cables.

Once measurements of EMF strengths are made in the field, they can be compared to the reported electro- or magneto-sensitivity of different fish or benthic organisms likely to be found within or travelling through the proposed project area. In this way, the likelihood that EMFs from submarine cables could be detected by and potentially alter the movement or migration of local fish species could be evaluated and best management practices put in place to reduce any anticipated interference. Beyond this, seasonal baseline or pre-construction fish community surveys throughout the project area and along the proposed cable route would be needed to establish whether EMF-sensitive species inhabit or move throughout the area. In order to definitively determine whether these species will be affected by EMFs from the submarine power cables, however, field studies assessing the behavioural response of fish to the electric and magnetic fields from the cables during wind turbine operation are necessary. The behavioural response of local fish to EMFs could be elucidated by observing the reaction of individuals as

they approach the cables, by comparing the abundance and distribution of species in the vicinity of cables to their abundance and distribution in nearby control areas, or by conducting gradient analyses of how fish biomass and distribution vary as a function of distance to the cables. However, even with these types of targeted analyses, it will be difficult to isolate the effects of EMFs from operational noise effects. Addressing this challenge is discussed in more detail in the research needs section below.

5.6 Monitoring effects of local changes in water quality

As highlighted in our earlier report (Nienhuis & Dunlop 2011), there are a number of ways in which the installation of offshore wind power projects in the Great Lakes could impact local water quality, with potential consequences to fish and other aquatic organisms. Correspondingly, in order to assess the significance of these effects and determine whether preventative or mitigation measures are required for certain activities, monitoring would be warranted. However, most water quality impacts are expected to arise over the short-term during the construction phase, with increases in turbidity and potential sediment contaminant release being most probable during dredging or drilling operations. For this reason, effects monitoring for local changes in water quality should be intensively targeted around the specific operation of concern. To quantify the impact of these activities on local water quality, baseline measurements are first needed of relevant chemical (i.e. dissolved oxygen, nutrient and contaminant concentrations) and physical parameters (i.e. light penetration depth, secchi depth, and suspended solid concentrations) at various water column depths within the predicted area of impact, following standardized sample collection and analysis protocols. Having established background water quality conditions, comparisons can then be made with measured conditions during and after those construction activities resulting in sediment disturbance. Measured changes in water quality parameters could then be related to any observed differences in fish abundance or behaviour, presuming that fish surveys are conducted concurrently alongside water quality assessments. This was done at the Lillgrund offshore wind power project in Sweden, where investigators conducted trawling surveys following a BACI experimental design to assess the immediate, short- and long-term effects of dredging-related turbidity on the abundance of small fish in the area (Hammar *et al.* 2008).

To assess the potential for sediment-bound contaminants to be released upon dredging and subsequently taken up by fish or other biota, chemical analyses, sediment toxicity studies and bioassays should be performed on sediment cores collected throughout the project area prior to construction (U.S. Department of Energy 2009). Guidelines and protocols for these types of studies have been well-established and could be applied to sediment cores collected at prospective sites for wind power projects in the Great Lakes (e.g. Munns *et al.* 2002). If a project proceeds in an area where some contaminated sediments exist, a BACI-type experimental design that includes non-dredged reference sites might be most appropriate for testing the ecological impacts of dredging-related resuspension as it has been used with demonstrated success in the recent past (Knott *et al.* 2009). Sessile, filter-feeding invertebrates are generally thought to be good indicators for environmental contamination, and would be a good initial choice for monitoring potential contaminant uptake from dredged sediments in the Great Lakes. However, if these studies indicate that there is a concern for bioaccumulation, an additional option would be to monitor contaminant concentrations in local fish because their consumption could pose a health risk to humans.

5.7 Quantifying the effects of introduced hard substrate on local biota

While turbine foundations and scour protecting materials could create novel habitat for certain Great Lakes fish and aquatic invertebrates, there is a pronounced lack of knowledge regarding the potential effects that these artificial hard substrates will have on both fishery resources and on the spread of invasive species, among other things. Targeted monitoring studies of local fish and benthic invertebrate communities associated with these structures will therefore be vital to addressing some of these knowledge gaps. Here again, comprehensive baseline assessments of the abundance, distribution and diversity of fish and invertebrates within the proposed project area are needed to serve as a basis for comparison with post-construction monitoring, and to ensure that any community changes resulting from the presence of wind turbines can be detected. However, as noted above, it can often take many years after an impact (in this case the introduction of novel substrate) to detect successional changes in invertebrate communities or changes in the abundance and diversity of local fish assemblages. For this reason, longer post-construction monitoring would be warranted to assess the habitat creating potential of wind turbine foundations; this could very well serve to benefit proponents wanting to document and

showcase the positive aspects of turbine installations, and could help to inform future developments.

Approaches to monitoring the development of fouling communities on submerged turbine structures are relatively straightforward owing to the fact that most epifaunal invertebrates are sessile or slow moving. A commonly employed method at marine wind power projects is to use underwater cameras to periodically capture either video or pictures of the foundation surfaces that can subsequently be analyzed to identify species composition and percent coverage (Kjaer *et al.* 2006). Alternatively, divers can visually observe and record the species present or collect representative samples to be analyzed in the lab for estimates of biomass, diversity or even individual growth rates (Wilhelmsson & Malm 2008).

A gradient design approach to assess the extent of the impact that turbine foundations and scour protection could have on infaunal or epibenthic invertebrate communities might be the best option. This has been done to test the effects of newly installed offshore gas platforms on benthic communities which might be similar to those anticipated from the installation of offshore wind turbines. In one such recent study (Manoukian *et al.* 2010), sediment samples were taken at increasing distances from each platform, and the organisms within them identified and counted to obtain measures of species abundance, diversity and evenness—all good biological indicators of environmental impacts. Pre- and post-construction infaunal community surveys were conducted in a similar manner throughout the wind power project area at both Horns Rev and Nysted, although here investigators followed more of a BACI-type design (Kjaer *et al.* 2006). In these surveys species biomass was additionally determined, which is another useful biological metric for comparing between sites or before or after an impact.

The effect of the introduction of artificial hard substrates on fish, which could include an artificial reef or fish attraction effect, will likely prove less straightforward to monitor than impacts on benthic invertebrate communities. Not only are fish mobile, utilizing different lake habitats through the year or even across a 24-hour cycle, but they also occupy three-dimensional space as opposed to the two-dimensional space occupied by fouling or benthic invertebrates, making them more difficult to monitor. In addition, the potential attraction effect that the introduced hard substrate and vertical relief associated with wind turbine foundations might have

on fish could be confounded by other effects from operating wind turbines, such as noise and EMFs which could result in avoidance. These potential confounding effects on fish behaviour might not easily be controlled, but should certainly be considered in the context of assessing the artificial reef effect of turbine structures.

A number of studies have been conducted to evaluate the effectiveness of artificial reefs as fish-concentrating devices, both in marine systems as well as within the Great Lakes. The foundations and scour protecting material around turbine structures could act as fish aggregating devices as well, meaning that the methods employed in artificial reef monitoring studies could also be applied at offshore wind power projects. Fortunately, it has been demonstrated that fish aggregations tend to be localized near introduced hard structures. As a result, surveys to assess fish use or attraction to artificial structures can be targeted within and around them, reducing the spatial extent of sampling efforts required for reef monitoring studies. Consequently, visual techniques can be a feasible means of quantifying fish stocks near artificial reefs and have been used in many of the attempts to do so. For example, as part of a study to determine the sport fish attraction potential of two artificial reefs in Lake Erie, both stationary, and mobile underwater video surveys conducted by divers were used to identify and enumerate fish on a monthly basis at artificial reef sites and adjacent non-reef control sites (Kelch *et al.* 1999). Observations by scuba divers swimming along transects were similarly used to estimate the number and species of fish at artificial reef and reference sites (Kevern *et al.* 1985) as well as before and after reef construction (Creque *et al.* 2006) in monitoring studies of two different artificial reef projects in Lake Michigan. In order to investigate the potential for wind turbines to function as artificial reefs and fish aggregation devices, estimation of fish abundance and diversity at varying distances from turbines within two offshore wind power project areas in Sweden were also conducted by means of visual scuba census (Wilhelmsson *et al.* 2006) which was subsequently repeated several years later at one of those sites (Andersson & Ohman 2010).

While visual surveys can be very useful in this context, their major downfall is that they can only be conducted during the day and in water shallow or clear enough to enable the diver or camera to visualize the surrounding area. Recognizing these limitations, several artificial reef studies in the Great Lakes have combined daytime visual surveys with gill net sampling, where nets were set overnight or over a 24-hour period in order to ensure representative sampling of both diurnal

and nocturnal reef inhabitants (e.g. Creque *et al.* 2006; Kevern *et al.* 1985). More recently, the use of hydroacoustic methods has been promoted as an approach to improve the quantification of fish stocks near introduced hard structures (Hvidt *et al.* 2006; see section below).

In addition to assessing the fish aggregating effect of wind turbines, it would also be useful to determine whether local fish species actually use the newly created habitat for foraging or spawning activities. This should certainly be a focus of investigation if turbine foundations and scour protecting materials are designed specifically to enhance fish habitat so that proponents can evaluate the degree of success of their efforts. Evidence of spawning around wind turbines can most definitively be obtained if eggs or fry are found. At artificial reefs in the Great Lakes, evidence for spawning has been obtained from visual searches conducted by scuba divers during known spawning or egg hatching periods, by vacuum pumping rocky crevices to find and collect eggs, by deploying and checking fry traps around the area, or even using plankton nets to trawl for nearby fry (Kevern *et al.* 1985). Currently, however, the use of egg nets set and retrieved by scuba divers is the most commonly employed method for evaluating the use of reefs as spawning habitat (Fitzsimons *personal communication*). For deeper water reefs, remotely operated electrofishers with video and gang-line deployment of deepwater egg traps have also proven effective to evaluate lake trout reproductive activity (Riley *et al.* 2010). With regards to assessing foraging use or feeding behaviour of fish associated with wind turbine structures, the stomach contents of fish could be compared with reef epifauna or prey items or, alternatively, using lipid analysis or isotopic techniques (Linley *et al.* 2007). Finally, site fidelity or residency times of different fish species could be assessed using acoustic telemetry or mark-recapture studies (Linley *et al.* 2007), which could prove useful to determine whether or not species like lake trout are consistently attracted to spawn at these novel habitats.

5.8 Common approaches for monitoring fish populations

Above we reviewed several examples of specific monitoring approaches that could be employed to assess some of the potential impacts associated with wind power projects in the Great Lakes. While we have touched upon several of them already, in the next section we will describe several recommended monitoring protocols or survey techniques commonly employed by individuals or institutions engaged in fish community surveys within the Great Lakes, and highlight examples of where they have been used in baseline or effects monitoring programmes for wind power

projects. A summary of the advantages and limitations of different fish sampling techniques that could be employed for baseline and effects monitoring at offshore wind power projects in the Great Lakes is presented in Appendix C. Appendix B includes a reference guide to existing protocols and instruction manuals for commonly employed fish community survey methods, with emphasis on current standards for Great Lakes fisheries monitoring techniques.

Netting surveys

Fish community index netting surveys are commonly conducted by fisheries biologists to characterize the diversity of local fish assemblages, to assess the relative abundance or biomass of various fish species, and to track spatial or temporal changes in the population status of different species. A number of different netting techniques and gears exist and have been used in Great Lakes fisheries surveys, as well as for baseline and effects monitoring of fish abundance and species composition within offshore wind power project areas in the marine environment. Generally, the choice of survey type will depend on the species and habitat being targeted.

Offshore areas

To monitor fish abundance and diversity in deeper or more offshore environments (see Nienhuis and Dunlop 2011 for a definition of nearshore and offshore), gill netting has become the standard approach, especially in freshwater lakes or reservoirs. Gill nets are nets with mesh sizes large enough for selected fish species to fit their heads through, but not their bodies. Because the gill flap or operculum of a fish gets snagged if it tries to back out, once encountered the fish cannot escape the net. Unfortunately, this can result in fish mortality depending on how long the fish are entrained, and for certain fish species this may not always be acceptable. Typical set times for nets range from several hours to more than 24 hours, although overnight sets lifted after approximately 12 hours are most common. Gill nets can be set on the lake bottom (bottom-set nets) to target more benthic oriented species or suspended from the surface (canned, suspended or pelagic nets) to target more pelagic species.

While single mesh-size gill nets are used to target species or individuals of a particular size, multi-mesh gill nets spanning a range of mesh sizes can also be deployed in order to more fully characterize the broader fish community. Fisheries biologists involved in the Ontario Ministry of Natural Resources' (OMNR) Broad-scale Fish Community Monitoring program employ both large and small mesh gillnets to target a broad range of species and acquire fish community data

at a landscape level (see Appendix B). In addition, multi-mesh benthic and pelagic gill nets have been used for a variety of scientific purposes to assess fish abundance and species composition during various phases of wind power project development in the marine environment. Examples include the use of multi-mesh gill nets for baseline fish community surveys at the Nysted offshore wind farm (Hvidt *et al.* 2003), as well as in studies to determine the effect of operational-phase noise on fish abundance at the Svante wind farm in Sweden (Westerberg 1999), and at Horns Rev to assess the role of turbine foundations and scour protection structures as artificial reefs (Leonhard & Pedersen 2005). In the latter example, 42 m-long multi-panel, multi-mesh gill nets were anchored on one end directly to the base of individual turbines, as well as being set in reference areas to test for differences in fish abundance owing to the artificial reef effect.

Trawl surveys, whether they are bottom trawls or pelagic trawls, have also been widely used in fisheries assessments (Appendix C). By design a trawl consists of towing a bag-shaped net behind a boat to catch any encountered fish larger than the mesh size, the key being to maintain the net at the desired depth for the targeted suite of fish species. Fish caught in this way can then be counted, identified and measured, and ideally released back into the lake. Annual prey or forage fish monitoring in offshore waters by the U.S. Geological Survey (USGS) Great Lakes Science Center (GLSC) has traditionally been conducted using a bottom trawl method, although more recently mid-water trawling and acoustic surveys have also been incorporated to provide a better measure of young of the year and other, more pelagic prey fish (Schaeffer *et al.* 2010; Warner *et al.* 2010). The methods employed for the GLSC surveys are described in individual status reports for each of the Great Lakes, presented annually to the Great Lakes Fishery Commission and available through the USGS.

Beam and otter trawls, both used for benthic trawl surveys, have also been employed in fisheries monitoring within offshore wind farm and reference areas in Europe, including at the Nysted and Horns Rev wind power projects in Denmark and the North Hoyle wind power project in the UK. In these examples, the choice of benthic trawl surveys reflects the fact that many species of commercial importance in these regions, including cod, sole, flounder, dab, turbot and plaice, are bottom-dwelling species and are best targeted using these methods. However, pre-construction beam trawl surveys at North Hoyle were found to have very low catches (Michel *et al.* 2007),

limiting comparability with post-construction monitoring data, while at Nysted trawling data suffered from low reproducibility (Hvidt *et al.* 2003), indicating that this gear type is not always reliable for monitoring purposes.

Nearshore areas

Recognizing their ecological importance and biological diversity, agencies are increasingly targeting smaller, nearshore fishes in their monitoring programmes, for example using multi-mesh gill nets such as the standardized NORDIC net, or broad-scale small mesh nets. Within several locations in the Great Lakes, the OMNR conducts variations on a small fish biodiversity survey, which includes multiple gear types such as small-mesh gill nets, seine nets, minnow traps, and fyke nets to capture species such as cyprinids, which aren't typically captured in traditional assessment nets. Fyke nets and fry fyke nets have also been used in baseline fish community surveys at proposed offshore wind power project sites, including the Nysted wind farm (Hvidt *et al.* 2003), in order to complement gill net and trawl surveys and more fully characterize local species assemblages in the area. Fyke nets were also used by the Swedish Department of Fisheries during the monitoring program at the Lillgrund wind farm (Andersson 2011).

To assess and monitor the status of nearshore sport and commercial fish species within the Great Lakes (and other locations), the OMNR conducts standard live release trap netting programs (Stirling 1999). Trap nets are size selective, tending to exclude very small fish. Standardized methods, gear descriptions and other technical information required to conduct Nearshore Community Index Netting (NSCIN) surveys are described in a manual available through the OMNR (see Appendix B). Surveys also exist that target certain species at critical periods, for example in OMNR's Fall Walleye Index Netting Program which uses large, multi-mesh gill nets to target walleye just prior to spawning (Morgan 2002; Morgan & Snucins 2005).

Fisheries acoustics

The application of fisheries acoustics (or more generally, hydroacoustics) is an emerging, and now often preferred, technique for fisheries research and assessment both within the Great Lakes and elsewhere. Acoustic methods allow for rapid assessments of fish abundance and distribution patterns over relatively broad spatial scales with the added advantage of being non-destructive to

the fish being sampled (Simmonds & MacLennan 2005). In essence, this technique employs the principles of sonar to detect fish or other objects having densities different than water both within the water column and along the lake bottom. An acoustic echo sounder mounted to a moving or stationary vessel emits a pulse or beam of acoustic energy into the water. The acoustic beam is cone-shaped, expanding with increasing distance from the source. For this reason, vertical or down-looking hydroacoustics are most commonly employed in deeper waters and for non surface-oriented pelagic species, while horizontally aimed or side-scan transducers are more appropriate in shallower water or for species found closer to the water surface (Taylor & Maxwell 2007). When the pulse or beam of acoustic energy encounters an object, some of the energy gets reflected back to a transducer which detects and converts the returning echoes to electrical signals that can be processed and recorded by digital output devices.

The ability of a given target or object to reflect acoustic signals is largely proportional to its size (or the volume of its air bladder in the case of fish) meaning that estimations of fish size using hydroacoustic surveys are possible. In general, acoustic surveys are conducted along pre-defined transects within the area of study, over set periods of time. Owing to the fact that many species exhibit more tightly aggregated schooling behaviour during the day, which can make individual counts more difficult, many hydroacoustic surveys are conducted between the hours of dusk and dawn to capture those periods where fish are more highly dispersed, yet still active. However, the timing of sampling and the duration of individual surveys will always depend on the specific objectives of the monitoring programme.

Although hydroacoustic techniques can provide information on fish size, they cannot confirm fish identity directly (Appendix C). For this reason, sampling with more traditional fisheries assessment gear including gill or trawl nets is needed in conjunction with hydroacoustic surveys to verify the species composition in the area and calibrate the acoustic signals. In this way post-processing and analysis of hydroacoustic data can also provide estimates of species composition, in addition to reliable estimates of abundance and spatial and temporal distribution patterns. Depending on the frequency of sound used, fisheries acoustics can also provide information on both large and small fish, as well as invertebrates such as plankton. Higher frequencies allow an assessment of smaller species like small prey fish and invertebrates while the lower frequencies provide an assessment of larger fish such as the species targeted by anglers.

Acoustic surveys are also a valuable means of mapping the lake bottom. Here again, once field calibrations are made to ground truth the hydroacoustic data (often accomplished using underwater video cameras), sonar scanning of the lake bottom can provide detailed information on the relative size-distribution and composition of the substrate, and even on the density and distribution of aquatic plants.

While a significant degree of technical expertise is required to conduct the field surveys and to analyze the resulting data, hydroacoustics represents a highly valuable, yet cost-effective and non-destructive tool for both fisheries surveys and habitat assessments. Because it is usually possible to sample much more of the lake, sample the entire water column at once, and not be confounded by issues of net selectivity and avoidance, fisheries acoustics can provide more accurate estimates of fish abundance, density and distribution than traditional netting alone. Furthermore, one of the real strengths of using fisheries acoustics is that it can give you a simultaneous view of almost the entire ecosystem, from habitat (including substrate and aquatic plants) to invertebrates to fish; in this way it can be very cost effective, as well as providing useful information on associations among species and between species and their habitat. For these reasons, hydroacoustic monitoring has been employed to study potential impacts of offshore wind power projects to fish populations in marine systems (Box 1) and will no doubt have an important role to play in baseline surveys and monitoring of effects in the Great Lakes.

Combined with more traditional supplementary field surveys, hydroacoustic monitoring could provide much of the information on fish abundance and distribution, and on benthic habitat conditions required for both pre-construction baseline surveys and for effects monitoring studies at offshore wind power project sites in the Great Lakes. Prompted by the need to ensure standardized assessment approaches, the Great Lakes Fishery Commission (GLFC) recently funded a study group on hydroacoustics. The resulting report (Parker-Stetter *et al.* 2009) summarizes standard operating procedures and recommendations for the analysis of acoustic-survey data in the Great Lakes, and is available through the GLFC (see Appendix B). This document, along with several related documents that have been published in the literature (i.e. Rudstam *et al.* 2009) present the best available guidelines and best management practices for

hydroacoustic surveys in the Great Lakes and should be consulted by proponents considering these types of surveys at proposed wind power project locations.

Box 1: Hydroacoustic monitoring at Horns Rev wind farm

At the Horns Rev offshore wind power project investigators carried out fisheries acoustic surveys to assess the impact of wind turbines on local fish communities. Horizontal acoustic surveys were conducted both inside and outside the project area during the fall when the greatest densities of fish were expected to inhabit the region (Hvidt *et al.* 2006). The sampling approach consisted of both control-impact and gradient-type designs. Hydroacoustic surveys were conducted along four parallel pairs of 2 km-long transects covering the impacted (i.e. inside the wind farm) and reference areas (sites located 3-7 km away from the wind farm with comparable depth and substrate regimes), as well as along two perpendicular gradient transects extending across and an additional 2.5-3 km outside the wind power project (see below). Transects within the wind power project area were placed parallel to turbine rows at approximately 50 m from individual turbines to ensure that the acoustic beam covered the foundations. At all transects, surveys were conducted both during daylight and night-time to account for differences in diel activity patterns across fish species. In order to identify the relative species composition in the area and to validate the hydroacoustic size frequency data to individual fish species, traditional netting techniques were also used as part of the study.

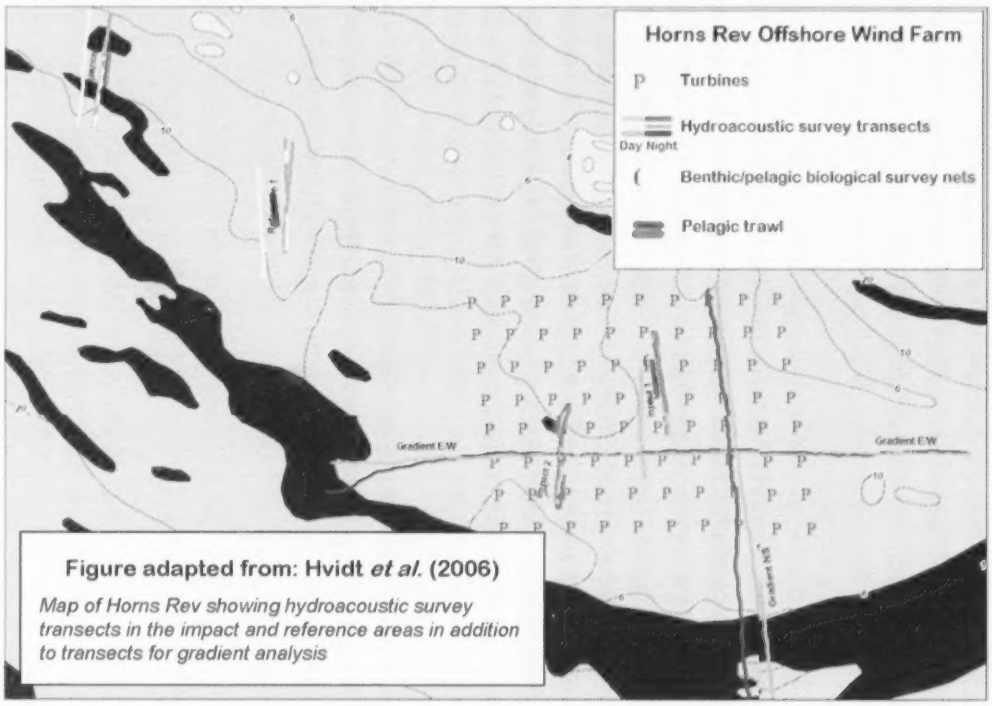


Figure adapted from: Hvidt *et al.* (2006)

Map of Horns Rev showing hydroacoustic survey transects in the impact and reference areas in addition to transects for gradient analysis

There are several methodological issues with the study design that limit the conclusions that can be drawn. Most notably, the use of horizontal-directed sonar (instead of vertical sonar) and the spatial resolution of transects was not sufficient to permit a spatial statistics analyses of the data, which would have likely improved the ability to detect distributional effects. Nonetheless, the study demonstrates that hydroacoustics surveys hold considerable promise for analyzing effects and characterizing fish populations in the vicinity of offshore wind turbines.

In the end, because each fish sampling technique (i.e. visual surveys, netting, hydroacoustics) has its own advantages and disadvantages (Appendix C), it appears that a combination of fish sampling methods would be the most robust approach to monitoring the effect that wind turbine foundations have on local fish assemblages. For example, it has been recommended that where water clarity and depth allow, visual census techniques should be included as a necessary complement to more wide-screening fish sampling methods such as gill netting or hydroacoustic monitoring in order to fully understand how the presence of wind turbines influences fish (Andersson *et al.* 2007).

5.9 Cumulative impacts

In response to a growing awareness of the potential environmental significance of cumulative effects, most regulatory agencies involved in project approval processes (including both the Canadian Environmental Assessment Agency and the United States Environmental Protection Agency) now require that consideration of cumulative effects be included in environmental impact assessments for proposed development activities. As with other forms of development, predicting the potential cumulative effects of an offshore wind power project to Great Lakes fish and fish habitat can be very difficult to achieve with a high level of certainty.

The concept of cumulative effects follows from the recognition that the environmental impacts of a particular human activity are not manifested or experienced in isolation. Rather, they can combine or interact with the direct and indirect effects of other activities or environmental stressors or disturbances. Considering the potential effects of offshore wind power projects on Great Lakes fish and fish habitat, cumulative effects could arise as a result of combinations of development impacts alongside existing stressors acting on the aquatic ecosystem such as climate change, habitat loss, invasive species, over-harvest, and pollution. In addition, the environmental effects of individual wind power projects can interact with those resulting from other existing or imminent projects, causing additive effects that might be different in nature or extent from the effects of an individual project. Consequently, the combined effects of multiple projects could result in additional disturbances or benefits to the ecosystem which might not have been anticipated for single projects considered in isolation. In other words, the environmental impact of development projects can be individually minor, but collectively significant if they interact across both space and time.

Acknowledging the complex and often unpredictable ways in which ecosystems respond to the combined effects of multiple stressors resulting from human activities over both time and space, a universal or standardized approach to assessing or mitigating cumulative environmental effects has yet to be developed (Bruns & Steinhauer 2005). Instead, adaptive frameworks or guidelines to address and evaluate cumulative effects are the existing norm. To account for the current lack of information and high degree of uncertainty associated with cumulative effects, much of the published guidance related to cumulative impact assessments (CIA) integrates a precautionary approach (Department of Energy and Climate Change 2009). In general, CIAs require that the developer consider the maximal extent or cumulative zone of impact (Bruns & Steinhauer 2005) as well as the incremental impact of other past, present and reasonably foreseeable future projects or activities (U.S. Environmental Protection Agency 1999) within the vicinity of their site.

Defining the spatial boundaries or cumulative zone of impact will depend on the scale of the proposed development, the nature of the environmental effect and on the available information pertaining to past, present and future activities in the region. However this will likely comprise an area substantially greater than the proposed project area (Wilson *et al.* 2010). Because there is often insufficient information regarding future projects or activities to assess their potential cumulative impacts with the project being proposed, it is recommended that best professional judgement be employed (Federal Environmental Assessment Review Office 2003). Clearly, it is not possible for a developer to predict every activity or project that could possibly take place within the vicinity of their proposed site throughout the operational lifetime of the project. However, consultation with other local developers or with permitting or land use planning agencies to identify whether any proposals for developments in adjacent waters exist is a reasonable requirement to inform CIAs.

While the cumulative impact of multiple wind power projects might be additive for certain effects, for others there might be synergistic effects, meaning that the cumulative impact of two or more activities is greater than the sum of their individual effects (Department of Energy and Climate Change 2009). Because the interaction of effects is complex, and often non-linear, scaling up or extrapolating predicted effects from individual turbines to commercial-scale turbine

arrays and to multiple projects within a region rarely provides an appropriate assessment of cumulative effects.

The most reliable approach to assess and better understand the cumulative effects of multiple turbines or of multiple adjacent wind power projects is to conduct careful and comprehensive environmental monitoring as the projects are deployed. For example, baseline environmental assessments and a review of available historical data for the region can help proponents to identify and establish which activities or environmental stressors already exist within the proposed project area. This information will serve not only as a reference against which to measure cumulative impacts, but can also help to inform both the cumulative impact assessment process as well as decisions related to site selection and other mitigation strategies. Subsequently, continued effects monitoring at the site after development of the proposed project, as well as after the development of any subsequent and adjacent projects will be necessary in order to evaluate the cumulative environmental effects of individual or multiple wind power projects. Finally, in order to minimize cumulative effects through considerate spatial planning, developers and their consultants could be encouraged to work with other wind power proponents operating in the same region. Collaboration between proponents can also serve to coordinate and increase the efficiency of monitoring efforts, and improve the detection and mitigation any potential cumulative environmental impacts arising from their respective or combined activities.

6. Adaptive management and the precautionary approach

6.1 Taking an adaptive management approach

The lack of experience with wind facility development in the Great Lakes in addition to existing knowledge gaps related to the effects of offshore wind power projects on fish and fish habitat in general necessarily means that not all impacts can be anticipated and prevented *a priori*. For this reason, the adoption of an adaptive management approach could help address uncertainties about environmental effects and to learn from experience and inform future offshore wind development in the Great Lakes.

Adaptive management is a planned and systematic process to continually improve environmental management practices and decision making by identifying uncertainties, establishing methods to

test hypotheses related to those uncertainties, monitoring the outcome of different practices, and adjusting subsequent management actions based on the knowledge gained (Holling 1978; Walters 1986; Walters & Holling 1990). In this way, an adaptive management approach provides flexibility to modify a project and identify new mitigation measures in order to minimize or prevent unacceptable environmental impacts identified through monitoring or upon periodic review.

The general framework of an adaptive management approach is to define the desired outcome and performance goals (i.e. acceptable environmental impacts) of a proposed project or action, implement that action, conduct project monitoring to evaluate the results of that action against the environmental performance goals, modify or adjust the action accordingly, and then re-evaluate through additional monitoring. By repeating this cycle as the project moves forward, proponents gain valuable knowledge to reduce uncertainty related to environmental impacts and can therefore refine their actions to better reflect and meet the original objectives.

Within the context of offshore wind power project developments, adaptive management can be seen a tool for learning about and addressing the uncertainties associated with the potential environmental impacts of construction and operation. Thus, if the prospect of offshore wind power production in the Great Lakes is realized, an adaptive management process will be particularly valuable in the early stages of development and expansion when the first projects are granted approval and turbine installation is initiated. This will allow developers to take advantage of ongoing monitoring and research programmes to refine component designs or technologies and to develop more effective mitigation alternatives to reduce the environmental impact of future installations (U.S. Department of Energy 2009). In addition, as projects expand from individual pilot or demonstration projects to commercial-scale developments and eventually to a network of multiple projects, an adaptive management framework can also help to resolve uncertainties related to larger scale effects and cumulative impacts.

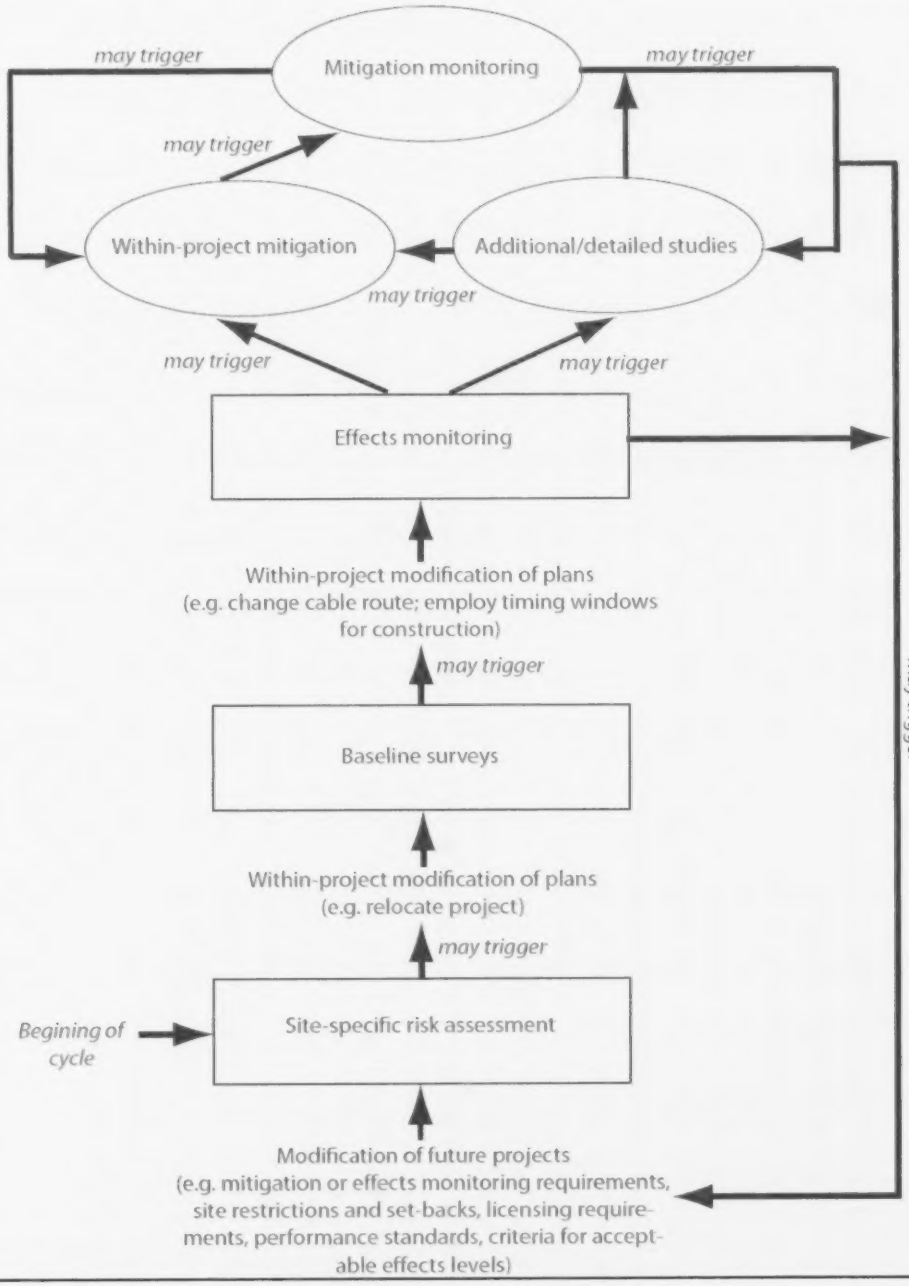
The U.S. Fish and Wildlife Service (USFWS) Wind Turbine Guidelines Advisory Committee (WTGAC) has outlined a tiered approach for assessing impacts to wildlife and their habitats (Wind Turbine Guidelines Advisory Committee 2010) that can be readily adapted for offshore wind developments in the Great Lakes. Reflecting the guiding principles of adaptive

management, the approach is an iterative process for collecting information and using that information to guide and inform appropriate siting, construction and operation decisions, and to evaluate alternative options to minimize risk. At each tier, potential issues associated with construction or operation are identified, and strategies to monitor and mitigate impacts are then formulated and put into place. Fundamental to such an approach is the collection of data in increasing detail as warranted by the results of environmental impact or risk assessments. For example, if early monitoring studies provide evidence that there are effects occurring that are of particular concern to fish or fish habitat, proponents would then follow up with more detailed studies to quantify those impacts, develop appropriate mitigation strategies or re-evaluate options for development. Adapting the tiered approach outlined by the WTFAC, we present a similar conceptual framework as an option for development of offshore wind power projects in the Great Lakes (Box 2).

6.2 Applying the precautionary approach

The precautionary approach (and its slightly stricter counterpart, the precautionary principle) recognizes that where serious environmental impacts might arise through human activities, lack of scientific consensus or understanding should not be used as an excuse to not take preventative measures to reduce the potential harm. The Precautionary Approach was a key part of the Rio Declaration, adopted by attendees (including Canada) of the United Nations Conference on the Human Environment, Rio de Janeiro, 3-14 June 1992. Principle 15 of the Declaration states "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations Environment Programme 1992).

Box 2: Conceptual framework for an adaptive approach to offshore wind power project developments



There are a number of ways in which the precautionary principle can be applied to offshore wind developments in the Great Lakes (Box 3). While the onus of conducting environmental risk or impact assessments for specific projects will likely fall upon the developers themselves, government or other regulatory agencies within the Great Lakes could also consider initiating broad-scale baseline fish community monitoring and habitat assessments in those areas determined to be feasible for development from a wind energy production point of view. In this way, areas housing sensitive habitat or species or that are otherwise at a significant risk from development activities can be pre-emptively identified and designated for protection, thereby becoming off-limits for wind power projects. At the same time, areas posing the least environmental risk or that are most suitable for wind power developments can also be identified and pre-selected. This type of pre-emptive inventory and analysis of habitats to identify avoidance areas is one of the key recommendations forwarded in a recent position statement by the Great Lakes Commission for jurisdictions responding to habitat alteration proposals involving wind power and other projects (Dempsey *et al.* 2006). Not only would such an initiative help to ensure the protection of valuable Great Lakes resources, but it would also relieve individual developers of the expense and effort of conducting baseline monitoring surveys at high-risk sites that would ultimately have to be abandoned. This approach has been taken by other jurisdictions (including Germany, Sweden and the UK) to support offshore wind development, and these examples can serve as a model for similar efforts in the Great Lakes.

6.3 Examples from other jurisdictions

There are a number of working models from other jurisdictions involved in offshore wind power production where the guiding principles of adaptive management and the precautionary approach have been incorporated into national strategies to promote the facilitation of offshore wind developments. Here we highlight some of the unique aspects and experiences of several countries where a sustainable approach to the implementation of offshore wind has been taken. With a focus on ecological research to inform environmental risk assessments and best management practices, these examples can provide useful guidance for wind power projects in the Great Lakes.

Box 3. Options for applying the precautionary approach for offshore wind power development in the Great Lakes

1. Identify areas where sensitive or ecologically critical habitats or species exist that might be particularly prone to disturbance or harm from offshore wind power activities. Limit or avoid development, make mitigation measures more strict, effects monitoring more detailed, or make licensing more difficult in those areas.
2. Conduct comprehensive risk assessments in advance of construction to identify areas, species or processes likely to be impacted by various development activities so that measures to reduce or avoid these impacts can be taken.
3. Proceed with caution when permitting projects to proceed, recognizing that a phased-in approach or slow expansion of development will facilitate comprehensive scientific study, applying lessons learned to future development, and using adaptive management.
4. Adopt certain mitigation measures when the best-available science indicates magnitude of effect is expected to be high, even if uncertainty exists as to the spatial or temporal scale of the effect.
5. Recognize that uncertainty exists and that comprehensive baseline and monitoring programs will be needed to fill knowledge gaps, especially in the early stages of offshore wind power project development within the Great Lakes.
6. Consider the deployment of pilot project and research platforms and fund research programs and technological development to reduce uncertainty for future offshore wind power projects.

Germany

The approach to offshore wind development taken by the German government (Köller *et al.* 2006) aims to ensure that that the growth of offshore wind power occurs in a scientifically informed and environmentally sustainable manner. Several aspects of the German strategy could be useful to inform responsible offshore wind development in the Great Lakes. Among these is a federal deployment strategy whereby the implementation of offshore wind power projects is tightly regulated, taking place in discreet phases. The idea here is that stresses to the ecosystem resulting from potential cumulative impacts of multiple simultaneous construction projects can be minimized by allowing the system time to recover between disturbance events. Furthermore, research into potential impacts can be focussed around the initial developments, and the knowledge gained can then inform environmental impact assessments, best management practices and mitigation measures for subsequent developments. This is a good example of both the precautionary principle and of adaptive management put into practice.

Accompanying the phased-in deployment strategy, the government has also funded and initiated an extensive ecological research programme. This multi-faceted programme includes the construction and monitoring of several offshore research platforms to assess the ecological impacts of various foundation types, research and development projects aimed at advancing

various environmental engineering aspects of offshore wind turbine components, and generic research and baseline investigations to characterize the reference state of the marine environment and identify suitable and off-limits areas for offshore wind developments. These government-funded research projects are being carried out in co-operation with various German research institutes, which not only ensures that the knowledge gained is accessible but also reduces costs to the developer and expedites the approval process. However, proponents of all planned offshore wind projects are required to carry out project-related baseline and effects monitoring studies, both within the wind farm as well as at reference areas, at the expense of the developer. With a focus on research to reduce the uncertainties associated with ecological effects from wind farms, this model has proven effective at promoting and facilitating the development of offshore wind, in addition to increasing public approval.

Sweden

To enhance the understanding of potential ecological impacts and support the development of offshore wind power, the Swedish government initiated "Windpilot-project" by granting partial funding to two wind farms, Lillgrund and Utgrunden. As part of this initiative, a large-scale research programme (VINDVAL) was also launched in collaboration with the Swedish Environmental Protection Agency to assess all relevant aspects of the environmental impacts of wind, with a focus on the effects studied at the two pilot wind farms. Conducted by research institutes, universities and environmental consultants, the results of many of these studies are readily accessible. The knowledge gained by conducting extensive research at these commercial-scale offshore wind power facilities both before, during and after construction has and continues to guide environmental impact assessments at other facilities. In addition the government has also commissioned the Swedish EPA to conduct an ecological inventory of offshore areas where wind development would be feasible and identify areas of high priority for protection. Finally, offshore wind developers are required to undertake their own project-specific environmental impact assessments and to conduct all necessary monitoring studies during construction and operation as outlined in their permitting conditions.

United Kingdom

The United Kingdom has recently emerged as one of the major global producers of offshore wind power, but has also concurrently developed a unique approach to supporting environmental

research efforts. Specifically, the Crown Estate has established a trust fund based on the accrued interest of refundable financial deposits made by developers to support various research programmes related to offshore wind. These funds are administered to environmental consultant and university research groups by COWRIE (Collaborative Offshore Wind Research Into The Environment), a registered charity set up to advance and improve knowledge of the potential environmental impacts of offshore wind development in UK waters. COWRIE has identified several key priority areas for research, included among them studies on the potential impacts of EMFs on fish, and the effects of noise and vibration on marine organisms. In addition to providing open access to the resulting research reports, COWRIE also hosts workshops to promote the sharing of knowledge, and supports public education efforts, among other things.

The UK has also implemented a phased-in approach to offshore wind power development as part of a strategic framework for the offshore wind industry. In Round 1, developments were limited in size and number, with the intent being to gain technical and environmental experience. Drawing from the lessons learned in the first round, the Department of Trade and Industry identified and initiated Strategic Environmental Assessments at three areas where the potential for offshore wind was most promising. For Round 2, developers were able to tender for any site within the boundaries of the Strategic Areas outside of restricted areas. This approach was developed to minimize environmental risk, to enhance and build upon knowledge gained at each round, and to facilitate offshore wind development by expediting the leasing and planning consents process.

Finally, apart from ongoing government-funded research studies, individual developers are responsible to undertake detailed environmental baseline surveys to inform project-specific environmental impact assessments, and to carry out effects monitoring studies as required by their licensing conditions. By funding and fostering environmental research through a transparent collaborative, and following an adaptive management approach to phased-in development, the UK model presents a unique alternative that other jurisdictions could certainly learn from.

6.4 Importance of data transparency

If or when offshore wind power production becomes a reality within the Great Lakes and increasing numbers of turbines are installed, there will be a need to systematically compile not

only the knowledge acquired through generic research programmes initiated by government or other participatory institutions, but also the information and data resulting from project-specific monitoring studies conducted by individual developers. One option for doing this would be to develop an accessible database or information exchange network to facilitate the collection and dissemination of information related to offshore wind developments and their associated effects on Great Lakes fish and fish habitat. Of course, such a database should be continually updated as new information and data becomes available through ongoing site monitoring and research programmes. To be effective, however, this type of initiative will require collaboration and commitments on the part of many different interest groups including both developers and governments that span provinces, states and nations. Furthermore, in order to ensure consistency in data collection and reporting and improve the comparability and predictive value of results, it will also be important to develop and specify standards and minimum requirements for both monitoring and reporting.

Based on the existing European model for offshore wind, it seems that the most effective way for progress to be made as far as understanding, predicting and preventing potential adverse ecological impacts of offshore wind power projects within the Great Lakes is to promote the sharing of knowledge and experiences as they are acquired by participating developers and research groups. The more Great Lakes-specific information that becomes available, the better strategies can be developed to manage and implement offshore wind power projects within these important freshwater ecosystems. As the knowledge base expands, an adaptive management approach can be facilitated whereby the best-available procedures for monitoring, technologies to enhance benefits, and measures to avoid or mitigate negative impacts can be promoted and put into place for future projects. Although individual developers might be wary of sharing certain proprietary information, targeted data sharing and the exchange of knowledge ultimately benefits all stakeholders. For this reason, the dissemination of information and open access reporting should either be a requirement for all offshore wind proponents, or at least strongly encouraged and rewarded through government-funded financial or other incentives.

7. Knowledge gaps and research needs

7.1 Knowledge gaps

Despite the fact that a significant amount of research into the ecological effects of offshore wind has been conducted in recent years, reflected by the growing number of published reports in the scientific literature, there are many gaps in our understanding of the cause and effect relationships between offshore wind power project activities and impacts to fish and fish habitat. Even for those effects that have been the focus of targeted scientific studies, controversy regarding the relevance or significance to fish populations or habitats still exists. This is the case for marine systems where offshore wind facilities have been in existence and studied for more than a decade, yet an even greater knowledge gap exists when it comes to understanding the impacts of offshore wind power projects in the Great Lakes, where development has yet to begin. Even so, many of the uncertainties identified for existing wind power projects in the marine environment mirror those highlighted for potential developments in freshwater environments. One of the foremost, generic areas of uncertainty across regions relates to the current lack of understanding and uncertainty regarding potential long-term and cumulative impacts of offshore wind power projects on fish populations and habitat. Part of the problem is that appropriate assessment methods and monitoring tools to address these issues have yet to be developed or established. Clearly, collaborative research efforts, long-term monitoring studies and the exchange of knowledge are required in order to identify standardized assessment procedures and enhance our ability to forecast these effects.

In our review of the potential impacts of offshore wind power projects to Great Lakes fish and fish habitat (Nienhuis & Dunlop 2011), several effects were flagged as being associated with a high degree of uncertainty. Among these, the potential impacts of EMFs from submarine power transmission cabling and the effects of operational noise and vibration on fish behaviour and distribution both emerged as key areas of uncertainty. In addition, there is a high degree of uncertainty associated with the potential for turbine foundations and scour protecting materials to be colonized by invasive species or conversely to attract or create habitat for native Great Lakes fish species. Just as the ability of wind turbine foundations to act as artificial reefs and concentrate fish species remains unclear, so too does the related potential for turbine installations

to enhance recreational fisheries. Finally, it is difficult to predict whether or not offshore wind power project areas could serve as sanctuaries and enhance the biomass of certain fish species by virtue of acting as partial no-take areas for commercial anglers. Table 3 provides a summary of some of the key knowledge gaps and ways of addressing them.

Beyond the uncertainty associated with the impacts of offshore wind power projects on aquatic ecosystems, there are also fundamental knowledge gaps related to our understanding of certain basic aspects of fish ecology within the Great Lakes. For example, the specific habitat requirements, seasonal movement patterns and limiting resources for many Great Lakes fish species remain poorly understood. Furthermore, accurate estimations of current and historical abundance for many species are also lacking. These unknowns compound the problem of predicting the longer-term or population-level impacts that offshore wind power projects might have on Great Lakes fish and add to uncertainties regarding ideal placement of wind power projects so as to minimize environmental impacts. Clearly, more research is required to better understand the existing status and trends of those species potentially impacted by offshore wind developments in order to improve projections of what those impacts might be and so that efforts to reduce harm to or enhance benefits for these species can be successful. Finally, significant gaps in lakebed research and habitat inventories throughout the Great Lakes basin also need to be addressed. The need for comprehensive aquatic habitat analysis and mapping in order to establish protection for sensitive and significant areas has been highlighted in the Great Lakes Fishery Commission position statement regarding policy recommendations and habitat guidelines for proposed lakebed alteration projects (Dempsey *et al.* 2006).

Table 3. Key knowledge gaps related to the effects of offshore wind power projects on fish and fish habitat in the Great Lakes. This list is not exhaustive. Priority levels are relative to other gaps in this table and depend on severity of effect, uncertainty level, and difficulty of conducting research to reduce uncertainty.

Knowledge gap	Priority level	Justification for priority level	Approaches for reducing uncertainty	Challenges	State of knowledge
What are the sensitivities of individual Great Lakes fish species to loud noise?	High	Magnitude of effect could be high; will enable prediction of severity of noise effects from construction to key species	• Laboratory experiments • *In situ* cage or mesocosm experiments	• Representative species from many taxa will need to be studied for a comprehensive catalogue	• Most laboratory studies have focused on marine fish; some Great Lakes fish have been studied, but many more remain to be studied
What is the effect of electromagnetic fields on fish distribution and behaviour?	High	Large uncertainty as to magnitude of effect; potential to affect Great Lakes species at risk	• Before/after impact studies throughout project area • Testing the sensitivity and response of individual Great Lakes species to EMFs in the laboratory • Gradient studies for existing power cables	• Disentangling from effects of operational noise or artificial reef effect in the field • Challenging to measure EMF strength at cable surface along lake bottom	• Many freshwater fish species can detect and respond to electric and/or magnetic fields • Fish particularly sensitive to electric and or magnetic fields include American eel, lake sturgeon, and salmonids • EMFs can interfere with early development and embryogenesis in some fish species
What is the effect of operational noise on fish distribution and behaviour?	Medium	Uncertainty as to magnitude of effect	• Laboratory studies of the effects of low frequency and low intensity noise on fish behaviour • Before/after impact studies throughout project area • Mesocosm studies to examine *in situ* impacts of similar types of noise	• Disentangling from effects of EMFs or artificial reef effect in the field	• Operational noise emitted into aquatic environment is higher than background noise levels and can be detected by fish up to tens of kilometres away • Anthropogenic noise can interfere with fish communication
To what extent will fish become acclimatized to noise from wind power projects?	Medium	Will determine the long-term consequences and severity of operational noise effects	• *In situ* tracking experiments • Before/after impact studies throughout project area • Laboratory studies to assess potential for habituation to similar types of noise	• Longer-term study potentially required	• Fish can acclimatize to sound, however almost nothing known specifically about long-term effects of wind power project noise

Knowledge gap	Priority level	Justification for priority level	Approaches for reducing uncertainty	Challenges	State of knowledge
What are the long-term effects from wind farms on fish population dynamics and recruitment?	Medium	Affects fundamental aspects of fish populations and fisheries; however, difficult to study	• Long-term before/after impact monitoring studies throughout project area	• Will need to monitor effects for many years	• Almost nothing known
What are the cumulative effects of multiple wind power projects?	Medium	Effects could be substantial depending on number of projects; however, difficult to study	• Predictive modeling • Before/after impact studies at multiple wind power projects	• Will need to monitor effects for many years and examine impacts over a broad spatial scale	• Almost nothing known
How will wind power projects impact coastal engineering processes?	Medium	Effects in marine systems have been minimal; however effects could be more significant in Great Lakes	• Predictive modeling • Before/after impact studies throughout area of impact	• Broad spatial scale should be considered	• For most marine wind farms, effects have been minimal; however, Great Lakes could be different
To what extent will impacts from noise and other effects deter fish from utilizing turbine foundations as artificial reef habitat (e.g. to forage, spawn etc.)?	Medium	Will determine habitat creation potential of turbine foundations	• Small-scale pilot projects or installations • Monitoring of turbine foundations	• Disentangling individual effects could be difficult • Long-term monitoring might be necessary • Cost of installation	• Catch rates of some marine species were significantly reduced within immediate vicinity of operating turbines but were substantially higher when rotor was stopped • Nothing known within Great Lakes context
What are the species-specific options for enhancing the habitat creation potential?	Medium	Will determine whether options exist to improve habitat creation potential of turbine foundations for desirable species	• Small-scale pilot projects or individual installations • Research at existing artificial reefs	• Long-term monitoring might be necessary • Cost of installation • Site-specific details will be important	• Some knowledge exists as to criteria for lake trout spawning habitat • Ongoing research into habitat restoration efforts including studies of several existing artificial reefs in the Great Lakes
Will the colonization of turbine structures by non-native species negate the habitat creation potential of offshore wind farms?	Medium	Will determine whether introduced hard substrates will be of overall net benefit or not	• Small-scale pilot projects or installations • Monitoring of turbine foundations • Research existing artificial reefs	• Disentangling from other effects, e.g. noise • Long-term monitoring required • Strongly dependant on local species pool	• The limited study of artificial reefs in the Great Lakes shows that fish still use reefs even when dreissenids present, with some costs • General impacts of most existing exotic species on spawning habitat of key species not known (independent of any wind farm related effects)

Knowledge gap	Priority level	Justification for priority level	Approaches for reducing uncertainty	Challenges	State of knowledge
To what extent will wind power projects act as sanctuaries from fishing and promote the build-up of fish biomass within the protected area?	Low	Benefits could be minimal if other impacts deter fish; longer-term study needed	• Before/after impact studies throughout project area and in reference areas • Predictive modeling	• Longer-term study required • Site-specific details will be important	• Marine reserves can enhance fish biomass and recruitment, with spill-over effects outside the reserve possible; however, it is not known whether wind power projects will be off-limits for fishing and have similar effects or whether fish will be deterred from the sanctuary due to other impacts

7.2 Research needs

There is an urgent need for research aimed at quantifying the degree of impact that different wind power related activities or installations will have on fish and fish habitat in the Great Lakes. Those areas associated with the greatest degree of uncertainty are of high priority for future research, and targeted studies or experiments to assess their impacts on various environmental receptors (i.e. individual fish, sedimentary processes, benthic invertebrate communities etc.) are warranted. A variety of research strategies or experimental approaches could be taken to address some of the key knowledge gaps and areas of uncertainty that have been identified. Below we review the types of scientific investigation that can be undertaken to elucidate some of the effects of offshore wind power projects to Great Lakes fish and fish habitat. A summary list, highlighting the usefulness and limitations of each approach, is presented in Table 4.

The challenges associated with large-scale field experiments can make effects monitoring difficult, especially in dynamic, open systems like the Great Lakes. For this reason, it might be desirable to supplement field studies with laboratory or mesocosm experiments to test the response of fish to some of the specific impacts that are likely to arise from wind turbine construction or operation. Certain impacts would be more amenable to laboratory studies than others, however. For example, it is relatively straightforward to test the hearing sensitivity or physiological tolerance of fish species to different noise sources and sound pressure levels in a laboratory setting. Similarly, the ability of different species and life history stages of fish to detect and respond to electromagnetic fields could also be investigated through laboratory experiments. On the other hand, it is not possible to study the response of fish communities or whole ecosystems to broad-scale changes in habitat wrought by the installation of large offshore wind power projects in the lab. Furthermore, the results of controlled laboratory studies are not always transferable to real-world situations where multiple variables interact to influence the response of organisms and systems to a given factor.

Mesocosm-type experiments where fish are held in field enclosures subject to site-specific environmental conditions and are subsequently exposed to effects related to wind turbine construction or operation might in some instances represent a good compromise between lab and field studies. Modelling studies related to changes in physical processes like current action and

sediment dynamics, for example, might also be useful to aid predictions of local, far-field, and potential long-term impacts from wind turbine installations. However, measurements conducted in the field will still be necessary to ground-truth or confirm the results of predictive models. Although supplemental studies can be undertaken to better quantify or predict the response of fish species to the impacts of offshore wind power projects, it is always important to acknowledge their respective limits and applicability.

Unfortunately, individual proponents are not likely to conduct independent studies beyond the project-specific monitoring required of them through their licensing agreements. For this reason, there is both a clear need and a unique opportunity for university or other government funded institutions or groups (with potential industry collaboration) to undertake supplementary laboratory or mesocosm-type studies to investigate species-specific responses to various wind power project related stressors. As a starting point, basic laboratory studies to assess the sensitivities, behavioural and physiological thresholds of Great Lakes fish species to stressors like noise and electromagnetic fields have yet to be conducted on a large scale. These types of studies are relatively straightforward, but the knowledge gleaned by conducting them can help to guide environmental risk assessments for offshore wind projects, and steer appropriate mitigation measures. Subsequently, mesocosm-type studies similar to those conducted for marine fish can also enhance our understanding of and ability to predict the impact that these novel stressors could have on representative Great Lakes fish species.

For example, many studies investigating the physiological effects of pile driving noise on marine fish species have involved holding fish in enclosures at increasing distances from the sound source and examining them after exposure. These types of *in situ* studies can improve our understanding of the physiological effects that pile-driving noise has on different species of fish at varying distances from the source, and under different site conditions including depth, substrate type and wave or current strengths. In addition, similar experiments to those in which caged fish were exposed to pile driving noise both with and without sound attenuation measures employed can demonstrate the ability of different mitigation options to reduce harm to fish. However, in order to avoid some of the problems identified with these earlier studies, it is critical that sound pressure levels be recorded at each exposure distance, that fish are handled and

examined following appropriate scientific protocols, and that proper replication is ensured (Popper & Hastings 2009).

While laboratory studies can identify which Great Lakes species are most likely to interact with EMFs, mesocosm experiments similar to those described in Gill *et al.* (2005) might be useful in order to visually observe the behavioural reaction of fish to EMFs within a partially controlled setting. In these experiments electrosensitive local fish species were held in field enclosures where they were exposed to typical cable-strength EMFs. Using implanted acoustic transmitters the movement of each fish was closely monitored and tracked, and then analyzed to determine whether the fish elicited a directional response to the simulated EMFs. In addition, specially designed field surveys such as those employed to assess fish behaviour in response to the power cable at Nysted (Kjaer *et al.* 2006) could also be a useful study model to adapt within the Great Lakes. Investigators there placed multi-directional fyke nets on either side of the submarine power cable in order to detect the migration direction of fish, and to estimate the number and identity of fish crossing the cable. Another interesting aspect of the survey of cable effects on fish at Nysted included a mark and recapture study for common eel in order to investigate the potential impact of the cable on the migration direction of this known EMF-sensitive migrant (Kjaer *et al.* 2006). Similar studies on American eel in the Great Lakes would be highly informative, and an option is to include impact monitoring for those offshore wind power projects with cabling installed in the vicinity of migration corridors.

Where generic laboratory or mesocosm studies will be necessary to understand the effects of specific activities on the behaviour and physiology of representative Great Lakes taxa, an understanding of the gross effects of various phases of wind power project development on local fish and fish habitat may be best achieved by initiating pilot or demonstration projects of varying scales and submitting them to extensive effects monitoring (see Table 4). Individual research platforms such as those deployed in Germany can provide valuable information on the colonization rates or local scour processes associated with different foundation designs or materials. In addition, noise measurements can be made during the installation of these individual foundations to provide a basis for noise attenuation models and predictions of the area of impact during pile driving activities, or to test the efficacy of various noise mitigation

strategies. However, in order to better understand the impacts of commercial-scale projects on local fish and fish habitat, larger pilot projects involving multiple turbines would be more useful.

Ultimately, comprehensive baseline and long-term effects monitoring at full-scale offshore wind power operations in the Great Lakes will provide the most valuable information upon which to base predictions of effects and establish effective measures to prevent negative impacts at subsequently installed projects. However, the impacts to fish and fish habitat arising from wind power project construction and operation will be highly site-specific and scale-dependant. In addition, fish communities are not static and neither are their ecosystems, especially with community-shaping forces such as climate change and invasive species introductions increasingly at play within the Great Lakes. For this reason, the ability to forecast effects for individual projects will be enhanced by a breadth of information assimilated over time from various projects sited in differing regions throughout the Great Lakes. Consequently, the need for timely reporting of effects monitoring results and data sharing will facilitate well-informed decisions related to offshore wind developments in the Great Lakes.

Table 4. Summary of the types of scientific investigation that can be undertaken to elucidate the effects of offshore wind power projects on Great Lakes fish and fish habitat, highlighting the usefulness and limitations of each approach. Options are presented in an order of increasing cost and effort, reflecting a subsequent increase in the amount and value of information that can be acquired.

Type of investigation	What can be learned	Limitations
Desk-top study (literature review, review of relevant fisheries survey data)	• Identification of potential impacts and/or benefits of offshore wind power projects to fish and fish habitat; areas requiring further investigation • Population status and trends of Great Lakes fish species of economic or ecological importance; general information on distribution or habitat use; sensitivities of representative Great Lakes taxa to certain impacts	• Studies of impacts currently limited to marine systems and organisms; predictions of likelihood or significance of potential effects suffer from a high level of uncertainty • Cannot replace site-specific field monitoring of fish communities and habitat assessments, especially to identify the presence/absence of critical or regulated habitat or species at risk; information on general ecology and habitat requirements of many species still lacking
Modelling studies	• Noise attenuation/transmission loss through water under different conditions; projections of area/extent of hydroacoustic impact for different sound sources (i.e. pile driving) • Electrical engineering models can accurately predict EMF strength and attenuation with distance from the source • Changes in current strength, sediment dynamics and scour processes resulting from the presence of submerged structures under different conditions can be modelled in coastal engineering studies	• Measurements of sound source levels in the field required for model input; projections useful for risk assessments but physical noise monitoring still necessary for impact assessments • Difficult to predict potential additive effect or interaction of EMFs from multiple closely arrayed cables; depth of cable burial (and strength of emitted fields at sediment surface) could vary along proposed route and with time • Requires baseline studies of natural physical processes within the proposed project area under various seasonal/weather conditions; difficult to predict far-field and cumulative impacts

Type of investigation	What can be learned	Limitations
Laboratory experiments	• Behavioural/physiological thresholds or tolerance of representative fish species and life stages to potential stressors like noise, vibrations, EMFs, turbidity levels etc. • Settlement/colonization rates of invertebrate larvae on different substrate materials	• Response of organisms to individual stressors in a controlled setting can differ significantly to their response in a natural setting where conditions are highly variable and multiple stressors or environmental factors can interact • Potential for turbine foundations or scour-protecting materials to be colonized in the field will depend on highly variable local species pools and larval dispersal trends which are not easy to predict
Mesocosm experiments	• Behavioural/physiological response of representative fish species and life stages to noise or EMF levels projected to arise during wind power project construction or operation under local environmental conditions	• Behavioural response of caged fish might not accurately represent the reactions of unconfined animals • Difficult to scale up to population level (can't demonstrate changes in abundance and distribution) • Potential habituation to stressors not addressed
Installation and monitoring of individual offshore research platforms	• Noise and turbidity levels associated with the installation of different foundation types (monopile vs. gravity base); feasibility or effectiveness of different construction-phase mitigation measures in the field • Identity (species diversity) and colonization rates of fouling community on different foundation material types • Extent of scour around individual turbine foundations; changes to sedimentary processes and local current strength and direction from presence of submerged structure	• Individual platforms that consist only of a foundation and tower cannot be used to measure levels or investigate the effects of operational turbine noise or EMFs; invertebrate colonization rates or habitat use by local fish species could be significantly different when these effects are present • Cannot assess cumulative effects from the construction or operation of multiple turbines

Type of investigation	What can be learned	Limitations
Installation and monitoring of individual offshore research platforms (cont'd)	• Fish use or preference for scour protection structures comprised of different types and sizes of materials, or designed with different heights, slopes, and total surface area	• Long-term studies required to monitor invertebrate colonization rates, potential fish use of new habitat • Site-specific biotic and abiotic conditions will strongly influence findings; measured effects will depend on location and timing and cannot always be used to predict effects at other sites
Monitoring studies at small-scale pilot wind power projects	• Noise and turbidity levels associated with the installation of cables and different foundation types (monopile vs. gravity base); feasibility or effectiveness of different construction-phase mitigation measures in the field • Noise levels associated with operating wind turbines at different wind speeds; strength of EMFs from different cables • Extent of scour around individual turbine foundations; changes to sedimentary processes and local current strength and direction from presence of submerged structures; potential for additive or interactive effects from multiple turbines can be assessed • Changes in the distribution and abundance of local fish species resulting from the construction and/or operation of multiple wind turbines can be monitored • Identity (species diversity) and colonization rates of fouling community on different foundation material types • Fish use/preference for scour protection structures with different types and sizes of materials, different heights and slopes, and different configurations, shapes or layouts	• Duration of construction activities for several turbine units much shorter than for commercial scale projects; cannot assess the impact of prolonged and repeated disturbance on fish distribution and abundance • Operational noise from several turbine units might not reflect underwater sound levels and extent of hydroacoustic impact that could result from larger projects • Strength of emitted EMFs from power transmission cables changes with the voltage and amperage being carried, which in turn depends on the number of turbines generating electricity • Long-term studies required to monitor invertebrate colonization rates, potential fish use of new habitat • Site-specific biotic and abiotic conditions will strongly influence findings; measured effects will depend on location and timing and cannot always be used to predict effects at other sites

Type of investigation	What can be learned	Limitations
Monitoring studies at commercial-scale demonstration projects	• Noise and turbidity levels associated with the installation of cables and different foundation types (monopile vs. gravity base); feasibility or effectiveness of different construction-phase mitigation measures in the field • Noise levels associated with operating wind turbines at different wind speeds; strength of EMFs from different cables types and around multiple closely arrayed cables; feasibility and effectiveness of different operational-phase mitigation measures in the field • Extent of scour, changes in current velocity and sedimentary processes around individual turbine foundations and throughout the project area; potential for additive or interactive, as well as far-field effects from multiple turbines can be assessed • Changes in the distribution and abundance of local fish species resulting from the construction and/or operation of an offshore wind power project in the Great Lakes can be monitored • Identity (species diversity) and colonization rates of fouling community on different foundation material types • Fish use or preference for scour protection structures comprised of different types and sizes of materials, designed with different heights and slopes, and when multiple "reefs" are configured in different shapes or layouts, or are connected • Potential benefits to recreational fisheries and/or potential interference with commercial fisheries can be assessed	• Long-term studies required to monitor invertebrate colonization rates, potential fish use of new habitat, and changes in fish recruitment, biomass, populations and assemblages • Site-specific biotic and abiotic conditions will strongly influence findings; measured effects will depend on location and timing and cannot always be used to predict effects at other sites

8. Conclusions

Here we have presented the second of two science-based reports prepared by the Aquatic Research and Development Section of the OMNR for the Renewable Energy Program as part of a literature review-based project relating to offshore wind developments and effects on fish and fish habitat. In our first report, we identified the potential effects of offshore wind power projects in the Great Lakes on fish and their habitats. To our knowledge this represented one of the first extensive assessments of offshore wind effects focussed on freshwater ecosystems to date. Through a synthesis of the existing scientific and grey literature—reflecting for the most part the European experience with marine offshore wind developments—combined with knowledge of Great Lakes ecosystems and fish biology, we concluded that offshore wind facilities in the Great Lakes could have a number of effects, some negative and some positive, to fish and fish habitat. However, upon review it also became apparent that the probability, the spatial and temporal extent, and the significance of many of these effects for individual species, aquatic communities and especially the Great Lakes ecosystem remain uncertain.

Moving beyond a catalogue of potential effects, the purpose of this report was to examine the options available to monitor, quantify and better predict the effects identified in the first report, and to evaluate different strategies not only for avoiding or minimizing negative impacts but also for enhancing the potential benefits within a Great Lakes-specific context. Acknowledging the high level of uncertainty that currently exist in predicting effects—especially indirect, cumulative and long-term effects—we highlight the role that adaptive management and a precautionary approach can play in informing future offshore wind development in the Great Lakes. Finally, we have listed some of the key knowledge gaps in our understanding of potential impacts of offshore wind power projects on Great Lakes fish and fish habitat, focussing on the need to share and disseminate knowledge as it is gained, and indicating priority areas for future research. In fact, the need for more research in this field cannot be expressed enough.

Given that the current state of knowledge related to ecological effects of offshore wind in the Great Lakes is based largely upon desk-top studies or literature reviews, many of the potential effects of offshore wind power projects to fish and fish habitat cannot be predicted with certainty

at this point. Laboratory and modelling studies can contribute valuable information to enhance predictions of the likelihood or magnitude of certain effects, and can be conducted with minimal cost and low risk (see Table 4). These types of studies would therefore be worth initiating to fill some of the gaps in our knowledge before developments begin. Models and conceptual desk-top exercises also help considerably with understanding the mechanisms involved in producing a particular environmental effect, identifying which knowledge gaps are particularly important to fill, and clarifying what the question being asked is in the first place. However, as the experience in the marine environment has shown, many offshore wind power project-related impacts can only be understood and quantified through *in situ* environmental effects monitoring both during and after construction. That is, we cannot fully understand the environmental impact that a wind power project will have until we are able to study the response of the local system to the construction and operation of an actual installation in the field.

As discussed above, individual research platforms and small-scale pilot projects could represent the next step towards understanding certain local effects, testing the feasibility of different mitigation measures related to construction activities, or evaluating the habitat creating potential of different materials, for example. Ultimately, however, the greatest and most valuable knowledge would be gained through focussed research and monitoring at commercial-scale demonstration projects throughout the construction phase and over the long-term during operation. Looking ahead, collaboration between government, industry and academic partners to plan and initiate this type of project would be highly valuable.

Focussed research related to offshore wind effects on fish within a Great Lakes setting can also help identify the need for or promote the development of targeted mitigation strategies. As identified in this report, there are a variety options available to avoid or minimize a number of impacts that could have negative consequences for local species and habitat resources. Of these, the importance of selecting appropriate locations and abiding biologically relevant in-water construction timing windows so as to reduce disturbance to critical habitat areas and sensitive species or life stages must be emphasized. To be effective, this preventative strategy will require more accurate estimates of current and historical abundance, more information related to migratory corridors and seasonal movement patterns, and a better understanding of the habitat and resource requirements, preferences and limitations of local Great Lakes fish species likely to

be affected by offshore wind developments. This is why thorough, multi-season baseline fish community surveys and habitat assessments throughout a proposed project area will be so critical. In addition, broad-scale biological surveys and habitat inventories conducted across the Great Lakes before approvals and developments begin could identify priority areas for protection as well as areas where minimal ecological effects from offshore wind developments are expected. As governments on both sides of the border consider the possibility of offshore wind power to meet national, provincial and state renewable energy goals, a concerted effort across jurisdictions to conduct these types of assessments would be highly beneficial and has been recommended by the Great Lakes Fishery Commission (Dempsey *et al.* 2006).

While we have conducted an extensive review of existing guidance and development strategies, it is beyond the scope of this project to recommend the adoption of specific best management practices, to establish policy recommendations, or to develop guidelines for offshore wind developments in the Great Lakes. Rather, the information presented in this report is meant to provide science-based options and scientific background information to inform the future development of policy and best management practices related to the environmental effects of offshore wind facilities in the Great Lakes.

Based on the findings of this report which emphasize scientific considerations related to fish and fish habitat, it is clear that there are a number of options to guide effective strategies for offshore wind development in the Great Lakes. If appropriate precautionary measures are taken to avoid or mitigate the impacts of potential harmful or disturbing activities, and implementation strategies are adapted to reflect an ever-growing knowledge base and accommodate the best available science-based options for mitigation, offshore wind power generation within the Great Lakes has the potential to be implemented with minimal impacts on the aquatic ecosystem and in an environmentally sustainable manner.

Appendices

Appendix A. Sources and types of information available that could be consulted as part of preliminary offshore wind power project site assessments to help guide monitoring and mitigation strategies. Adapted from Ministry of Transportation of Ontario (2009).

Source	*Type of information that may be available*
Fisheries and Oceans Canada (DFO) • Aquatic SAR maps, SAR database • Various studies and reports • Practitioners Guide to Habitat Compensation, Operational Statements	• Spawning and nursery habitat characteristics of Great Lakes fishes • Species at Risk information and mapping • Compensation options, timing considerations

Ministry of Natural Resources (MNR)
• Consultation with relevant ministry staff including Lake Management and Fisheries Assessment Units
• Annual/broad-scale fish community index netting survey reports
• Fisheries Management Plans and other conservation/monitoring plans and objectives
• Natural Heritage Information Centre (NHIC) database
• Natural Resource Values Information System (NRVIS) database
	• Great Lakes fish and fish habitat
	  ○ Distribution and abundance data for fish communities, thermal regime classification, spawning data
	  ○ Regulated/sensitive habitat mapping
	  ○ Rare species information (SAR)
	  ○ Stocking, hatchery information
	  ○ Important angling areas, fish sanctuaries
	• Stewardship and habitat enhancement/restoration initiatives, Fisheries Management Plans

Environment Canada • Fact sheets • Federal water quality monitoring/Great Lakes Water Quality Agreement • Lakewide Management Plan publications • State of the Great Lakes reports	• Species distribution and habitat requirements • Areas of Concern within the Great Lakes • Great Lakes aquatic habitats, biotic communities, invasive species, resource utilization
Ministry of the Environment (MOE) • Provincial water quality monitoring system • Great Lakes restoration project plans	• Potential contaminant site information • Contaminant levels in sport fish

Source	*Type of information that may be available*
Ministry of Transportation • Fisheries and Aquatic Ecosystems studies • Environmental Guide for Fish and Fish Habitat • Other consultant reports and information	• Fisheries and habitat • Geotechnical, water body and contaminant information
Great Lakes Commission • Great Lakes Information Network (GLIN) • Environmental Monitoring Inventory for the Great Lakes • Great Lakes Coastal Data Model • Habitat Priority Planner tool	• GLIN maps and GIS, geospatial data for Great Lakes, lake topography and other data layers • Information on ongoing monitoring programs within the Great Lakes • Datasets related to Great Lakes geomorphology, transportation features, biologic observations • Spatial decision support tool to help planners prioritize habitat sites and conservation measures • Areas of Concern
Great Lakes Fishery Commission (GLFC) • Consultation with Lake Committees • Annual reports • Fact sheets	• Great Lakes fish and fish habitat ◦ Distribution and abundance data for fish communities in each of the Great Lakes ◦ Population status and trends for various species ◦ Plans for and results of fish population restoration or rehabilitation efforts
U.S. Geological Survey (USGS) Great Lakes Science Center (GLSC) • Atlas of the spawning and nursery areas of Great Lakes fishes • Summary reports of fish community surveys • Restoration plans • Great Lakes Aquatic GAP program databases and reports	Fish and fish habitat information ◦ Known spawning and nursery habitat areas and characteristics for various species ◦ Annual abundance data for various demersal, pelagic and prey or forage fish species ◦ Coastal habitat classifications • Aquatic biodiversity and habitat quality, invasive species population monitoring • Aquatic invertebrate distributions, identification keys

Source	*Type of information that may be available*

Conservation Authorities
• Fisheries Management Plans and other conservation and monitoring plans and objectives
• SAR databases and risk reach mapping
	• Fish and fish habitat information
	  ◦ Fish community data, spawning data, Migration information
	  ◦ Critical or specialized habitats
	  ◦ Known and potential presence of significant species and habitat features, sensitivities etc
	• Aquatic Species at Risk Mapping
	• Conservation Authority Values mapping for specific areas

Royal Ontario Museum, Canadian Museum of Nature	• Distribution, natural history and habitat requirements for Great Lakes fish and invertebrate species

Other interest groups and resource users
• Municipalities
• Recreational anglers/angling groups and outfitters
• Commercial fisheries
• First Nations communities, anglers, groups
• Stewardship groups, naturalists
• Ontario Federation of Anglers and Hunters
• Universities and colleges
• Ontario Hydro
• Ontario Power Authority
• Knowledgeable local residents/landowners
	• Fisheries and habitat
	  ◦ Habitat use, species distribution, population trends, spawning and migration information
	  ◦ Regionally rare species
	  ◦ Invasive species
	• Location of popular or traditional fishing sites
	• Stewardship and habitat restoration/enhancement initiatives and projects
	• Navigation maps
	• Barriers to movement
	• Location of water intake structures

Appendix B. Quick reference guide of existing environmental assessment methods, survey standards, and mitigation options. Selected examples of recorded guidelines and standards for assessing the environmental impacts of offshore wind power projects, methods and standards for Great Lakes fish community inventories and habitat assessments, and technical guidance and recommendations for mitigation options, habitat enhancement strategies and assessing cumulative impacts. This list is not exhaustive. It is intended to highlight a number of existing, open access and relevant references for offshore wind developers or regulatory agencies, reflecting wherever possible the most recent guidelines or requirements at the time of publication.

Subject area	Source title	Institution	Type of information	Link
Environmental assessments for offshore wind power projects	• An Assessment of the Environmental Effects of Offshore Wind Farms	• UK Department of Trade and Industry, Report (2000)	• Environmental assessment requirements, obligations for developers, key issues/ research needs	http://www.offshorewindenergy.org/reports/report_003.pdf
	• Offshore Wind Farms: Guidance Note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements	• UK Marine Consents and Environment Unit, Guidance Note (2004)	• Requirements for baseline and impact assessments, design and conduct of surveys, reporting	http://www.cefas.co.uk/publications/files/windfarm-guidance.pdf
	• Standard: Investigation of the Impacts of Offshore Wind Turbines in the Marine Environment	• German Federal Maritime and Hydrographic Agency, Standard (2007)	• Minimum technical requirements and procedures for implementation of baseline/effects monitoring, project assessment/reference areas, technical instructions for different survey types, sampling design, duration	http://www.bsh.de/en/Products/Books/Standard/7003eng.pdf
	• Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies	• US Department of Energy, Report (2009)	• Environmental impact assessment approaches, environmental monitoring for specific effects, the role of adaptive management, mitigation	http://www1.eere.energy.gov/windandhydro/pdfs/doe_eisa_633b.pdf
Fish and fish habitat assessment requirements	• Eastern Conservation Authorities Fish and Fish Habitat Review Guidelines	• Ontario Eastern Conservation Authorities, Guidelines (2008)	• Minimum requirements under Fisheries Act for fish habitat assessments and mapping, fish community inventories, impact assessments, determining HADD	http://www.dsao.net/Resources/EasternCAMinStandardsFishFishHabitatGuideline_Draft%20March2008.pdf
	• Ministry of Transportation Environmental Guide for Fish and Fish Habitat	• Ontario Ministry of Transportation, Guidance Document (2009)	• Fish community inventories, habitat assessments, baseline data collection, timing considerations for monitoring, impact assessments and mitigation	http://www.raqsb.mto.gov.on.ca/techpubs/eps.nsf/8cec129ccb70929b852572950068f16b/8d35d8cff877e2bb852572d7005a2a39?OpenDocument

Subject area	Source title	Institution	Type of information	Link
Fish and fish habitat assessment requirements	• Habitat Alteration and Assessment Tool	• Fisheries and Oceans Canada. HAAT Modeling Program (2001)	• Environmental assessment tool to assess impacts of large infills on fish and fish habitat, determine compensation, evaluate pre- and post-construction scenarios and changes in productive capacity of habitat, assess adequacy of habitat compensation	http://www.bio-software.com/hsm2/ (access password available from DFO)
Fish community survey methods or standards	• Manual of Instructions - Fall Walleye Index Netting (FWIN)	• Ontario Ministry of Natural Resources. Manual (2002)	• Standards for survey design and methods (overnight sets), gear descriptions (multi-mesh gill nets), field procedures, data management	http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@letsfish/documents/document/226868.pdf
	• Manual of Instructions - Nearshore Community Index Netting (NCIN)	• Ontario Ministry of Natural Resources. Manual (1999)	• Standards for survey design and methods (live-release trap netting), gear descriptions, field procedures, data management	http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@letsfish/documents/document/226869.pdf
	• Manual of Instructions and Provincial Biodiversity Benchmark Values: NORDIC Index Netting	• Ontario Ministry of Natural Resources. Manual (2005)	• Standards for survey design and methods, gear descriptions (multi-mesh gill nets), field procedures, data management	http://www.laurentian.ca/NR/rdonlyres/F97A585D-7C9D-453C-ADCD-8920B293E47F/0/Nordic.pdf
	• Standard Operating Procedures for Fisheries Acoustic Surveys in the Great Lakes	• Great Lakes Fishery Commission. Special Publication (2009)	• Description of equipment, survey designs and protocols, system calibration, data collection, management and analysis	http://www.glfc.org/pubs/SpecialPubs/Sp09_1.pdf
	• Manual of Instructions for Broad-scale Fish Community Monitoring using Large Mesh Gillnets & Small Mesh Gillnets	• Ontario Ministry of Natural Resources. Manual (2011)	• Description of gear types, duration of sets, instructions for processing catch, data recording	http://mnronline.mnr.gov.on.ca/Document/View.asp?Document_ID=17629&Attachment_ID=37971
	• Protocol for the Detection of Fish Species at Risk in Ontario Great Lakes Area (OGLA)	• Fisheries and Oceans Canada. Research Document (2008)	• Protocols and methods for documenting and addressing fish SAR within project area, guidance on sampling gear, effort requirements	http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_026_e.pdf

Subject area	Source title	Institution	Type of information	Link
Mitigation options (general)	• 2006 Project Completion Report: Conserving Great Lakes Aquatic Habitat from Lakebed Alteration Proposals	• Great Lakes Fishery Commission, Position Statement (2006)	• Recommended guidelines for evaluating lakebed alteration projects and protecting bottomland resources, guidelines to avoid/mitigate impacts to the ecosystem; analysis of legal framework for regulating structures	http://www.glfc.org/research/reports/Dempsey.pdf
	• Ontario Operational Statements	• Fisheries and Oceans Canada, Operational Statements (2009)	• Prescribed mitigation plans to avoid HADD in Ontario i.e. Ontario in-water construction timing windows, methods to protect fish/fish habitat during high-pressure directional drilling, dredging, and underwater cable installation	http://www.dfo-mpo.gc.ca/regions/central/habitat/os-eo/provinces-territories-territoires/on/index-eng.htm
	• Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies	• US Department of Energy, Report (2009)	• Mitigation options to address specific environmental effects of offshore structures, the role of adaptive management in evaluating and mitigating effects	http://www1.eere.energy.gov/windandhydro/pdfs/doe_eisa_633b.pdf
	• Cape Wind Energy Project Final Environmental Impact Statement	• US Department of the Interior-Minerals Management Service, Environmental Impact Statement (2009)	• Description of environmental mitigation measures proposed for all potential effects during construction and operation of the Cape Wind offshore wind power project	http://www.boemre.gov/offshore/AlternativeEnergy/PDFs/FEIS/Cape%20Wind%20Energy%20Project%20FEIS.pdf
Mitigation options (specific effects)	• Final Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish	• California Department of Transportation, Technical Guidance Manual (2009)	• Measures to avoid or minimize pile driving impacts, best management practices, performance standards, methods to measure and calculate underwater noise levels	http://www.apevibro.com/pdfs/Guidance_Manual_Sound_and_Underwater_Piledriving.pdf
	• Assessment and Costs of Potential Engineering Solutions for the Mitigation of the Impacts of Underwater Noise Arising from the Construction of Wind Farms	• UK Collaborative Offshore Wind Research Into the Environment, Report (2007)	• Setting targets for noise mitigation, methods to reduce underwater noise, assessment and need for further development	http://www.offshorewindfarms.co.uk/Assets/COWRIE-ENGFinal270907.pdf

Subject area	Source title	Institution	Type of information	Link
Mitigation options (specific effects)	• A Baseline Assessment of Electromagnetic Fields Generated by Offshore Windfarm Cables: Final Report • Technical Guidelines for Environmental Dredging of Contaminated Sediments	• UK Collaborative Offshore Wind Research Into the Environment, Report (2003) • US Army Corps of Engineers, Technical Report (2008)	• Suggested methods to measure EMFs in the field, guidance on mitigation measures to reduce EMFs generated by offshore windfarm power cables • Sediment sampling equipment and techniques, control measures for sediment resuspension and contaminant release	http://www.offshorewindfarms.co.uk/Assets/1351_emf_research_report_04_05_06.pdf http://el.erdc.usace.army.mil/elpubs/pdf/trel08-29.pdf
Artificial reefs	• International Position Statement and Evaluation Guidelines for Artificial Reefs in the Great Lakes	• Great Lakes Fishery Commission, Special Publication (1990)	• Acceptable materials, considerations for siting, recommendations for pre- and post-construction monitoring and evaluation	http://www.glfc.org/pubs/SpecialPubs/Sp90_2.pdf
Cumulative impacts	• Reference Guide: Addressing Cumulative Environmental Effects	• Canadian Environmental Assessment Agency, Reference Guide (2004)	• Framework for addressing cumulative environmental effects, determining significance of effects, mitigation, identifying future projects to be considered in environmental assessment	http://www.ceaa.gc.ca/013/0001/0008/guide1_e.htm#1

Appendix C. Summary of the advantages and limitations of different fish sampling techniques that could be employed for baseline and effects monitoring at offshore wind power projects. Methods listed first include those most commonly employed both for monitoring studies at existing offshore wind power projects as well as for fish community surveys within the Great Lakes, followed by several additional sampling methods that could be used.

Fish survey type	Examples of where employed	Advantages	Limitations
Visual surveys • Underwater cameras	• To monitor invertebrate colonization/community succession on submerged turbine structures; to assess fish use of artificial structures in the Great Lakes	• Photos or video can be analyzed to identify species abundance/diversity without requiring prolonged in-water time for divers; cameras can document local fish presence continually (i.e. in the winter or when weather conditions render netting or diving too risky); non-obstructive method will not harm or scare fish away	• Spatial coverage limited to area within viewing range of camera; not useful at night, under turbid conditions or at depths where light/visibility is limited (unless equipped with light source)
• SCUBA diver surveys, visual transects	• To monitor epibenthic and epibiotic invertebrate assemblages on or around submerged turbine structures; to document fish use of artificial reef structures in the Great Lakes	• Spatial coverage enhanced by conducting visual surveys along transects as opposed to stationary cameras; aquatic species can be counted and identified; behaviour and habitat associations of fish can be observed; non-destructive survey method	• Diver access to sites can be restricted under hostile weather conditions; spatial coverage limited to area within viewing range of diver; ineffective at night, under turbid conditions or at depths where light/visibility is limited; some fish species may be scared away by presence of diver
Bottom trawl surveys (beam or otter trawls)	• To survey and monitor fish communities within offshore wind power project areas (North and Baltic sea) and at reference sites; to conduct annual forage fish monitoring in the Great Lakes (USGS); employed by Lake Ontario Management Unit for stock assessments (OMNR)	• Fish can be identified, counted and measured; good catchability and standardized abundance and biomass data for certain species including a number of commercially important species; standardized approach allows for comparison with historical stock assessments; low mortality to fish	• Low catchability for many pelagic species (not representative of entire fish assemblage in an area); disturbance to lakebed possible; applicability limited under certain lake-bed conditions; sampling near turbine foundations or cables risks gear entanglement; limited to ice-free seasons

Fish survey type	Examples of where employed	Advantages	Limitations
Gill netting (benthic and/or pelagic sets)	• To conduct baseline and post-construction monitoring of fish communities in wind farm and reference areas; to monitor fish abundance near wind turbine foundations; used in broad-scale fish monitoring programmes in the Great Lakes (OMNR)	• Fish can be identified, counted and measured; overnight or 24-hour sets capture both diurnally and nocturnally active species (not limited to daylight hours); multi-mesh gill nets can quantitatively sample fish of all sizes (good community representation); standardized approach allows for comparison with historical assessments; nets can be anchored on turbine foundations to assess artificial reef effect	• Can be a destructive sampling method with significant fish mortality; single mesh size nets target only species within specific size ranges; both benthic and pelagic sets required to representatively sample entire fish community; information on fish habitat associations limited; limited to ice-free seasons; difficult to get unbiased and reliable estimates of fish abundance and density
Hydroacoustic monitoring	• To assess density and distribution of fish within wind farm and reference areas; used for fish community monitoring surveys in the Great Lakes	• Allows for rapid and quantitative assessments of fish abundance and distribution patterns over relatively broad spatial scales; non-destructive sampling method; detects both benthic and pelagic species; not selective for species within a specific size range; not limited to daylight hours or by depth; can provide simultaneous information on habitat and prey enabling a holistic "ecosystem" assessment	• Companion netting needed to confirm species identity directly; requires personnel with technical expertise to conduct monitoring and analyze data; night-time surveys required for assessing pelagic schooling species
Fyke net sampling	• To sample fish in the littoral zone (shallow vegetated areas); to assess directional movement of fish species around submarine cabling	• Fish can be identified, counted and measured; many species use littoral zone for foraging or spawning; useful in capturing migratory species that follow the shorelines; could be useful for assessing impact of EMFs from submarine cables on movement patterns of certain species	• Not effective in deeper water; open-water pelagic species not represented; spatial coverage limited; use limited to ice-free seasons

Fish survey type	Examples of where employed	Advantages	Limitations
Pelagic trawl surveys	• Mid-water trawling to assess pelagic species for annual forage fish monitoring in the Great Lakes (USGS);	• Fish can be identified, counted and measured; good catchability for certain pelagic species; mortality to fish can be low; often the best available option for assessing pelagic schooling species when combined with hydroacoustic surveys	• Low catchability for benthic species (not representative of entire fish assemblage); sampling near turbine foundations risks gear entanglement; limited to ice-free seasons
Trap netting, minnow traps	• To assess and monitor the status of nearshore sport and commercial fish species within the Great Lakes; minnow traps used to target smaller or juvenile species	• Fish can be identified, counted and measured; minimal fish mortality; effective for cover-seeking nearshore species, smaller taxa and juveniles not targeted by other netting surveys; could be useful for assessing effects of submarine cables or habitat disturbance to nearshore fish communities	• Not effective in deeper water; open-water pelagic species not represented; spatial coverage limited; use limited to ice-free seasons
Electrofishing	• To conduct nearshore fish community assessments in littoral areas of the Great Lakes; to evaluate the status of fish communities and habitat productivity in Great Lakes Areas of Concern (DFO)	• Fish can be identified, counted and measured; when performed correctly results in no permanent harm to fish; fish can be captured in most nearshore habitats; various size ranges can be targeted; could be useful for assessing effects of submarine cables or habitat disturbance to nearshore fish communities	• Limited to shallow water areas (< 2 m); catch can be selectively biased as to fish size and species composition; spatial coverage limited; use limited to ice-free seasons
Seine netting	• To conduct nearshore surveys of small fish populations in the Great Lakes and Lake Simcoe	• Fish can be identified, counted and measured; results in minimal fish mortality; targets shoreline, small-fish communities excluded by other netting techniques; could be useful for assessing effects of submarine cables or habitat disturbance to nearshore fish communities	• Limited to shallow water areas and minimal vegetation; large, deeper-water species not targeted; spatial coverage limited; use limited to ice-free seasons

Appendix D. Scientific and common names of fish species listed throughout the report.

Alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
Asian carp (silver)	*Hypophthalmichthys molitrix*
Asian carp (bighead)	*Hypophthalmichthys nobilis*
Atlantic cod	*Gadus morhua*
Bluegill	*Lepomis macrochirus*
Brown trout	*Salmo trutta*
Common dab	*Limanda limanda*
Common sole	*Solea solea*
European flounder	*Platichthys flesus*
Freshwater drum	*Aplodinotus grunniens*
Gizzard shad	*Dorosoma cepedianum*
Lake sturgeon	*Acipenser fulvescens*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Largemouth bass	*Micropterus salmoides*
Mimic shiner	*Notropis volucellus*
Mottled sculpin	*Cottus bairdii*
Plaice	*Pleuronectes platessa*
Rainbow smelt	*Osmerus mordax*
Rainbow trout	*Oncorhynchus mykiss*
Rock bass	*Ambloplites rupestris*
Round goby	*Neogobius melanostomus*
Smallmouth bass	*Micropterus dolomieu*
Spot	*Leiostomus xanthurus*
Spottail shiner	*Notropis hudsonius*
Turbot	*Scophthalmus maximus*
Walleye	*Sander vitreus*
White crappie	*Pomoxis annularis*
White perch	*Morone americana*
White sucker	*Catostomus commersonii*
Yellow perch	*Perca flavescens*
Zebrafish	*Danio rerio*

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